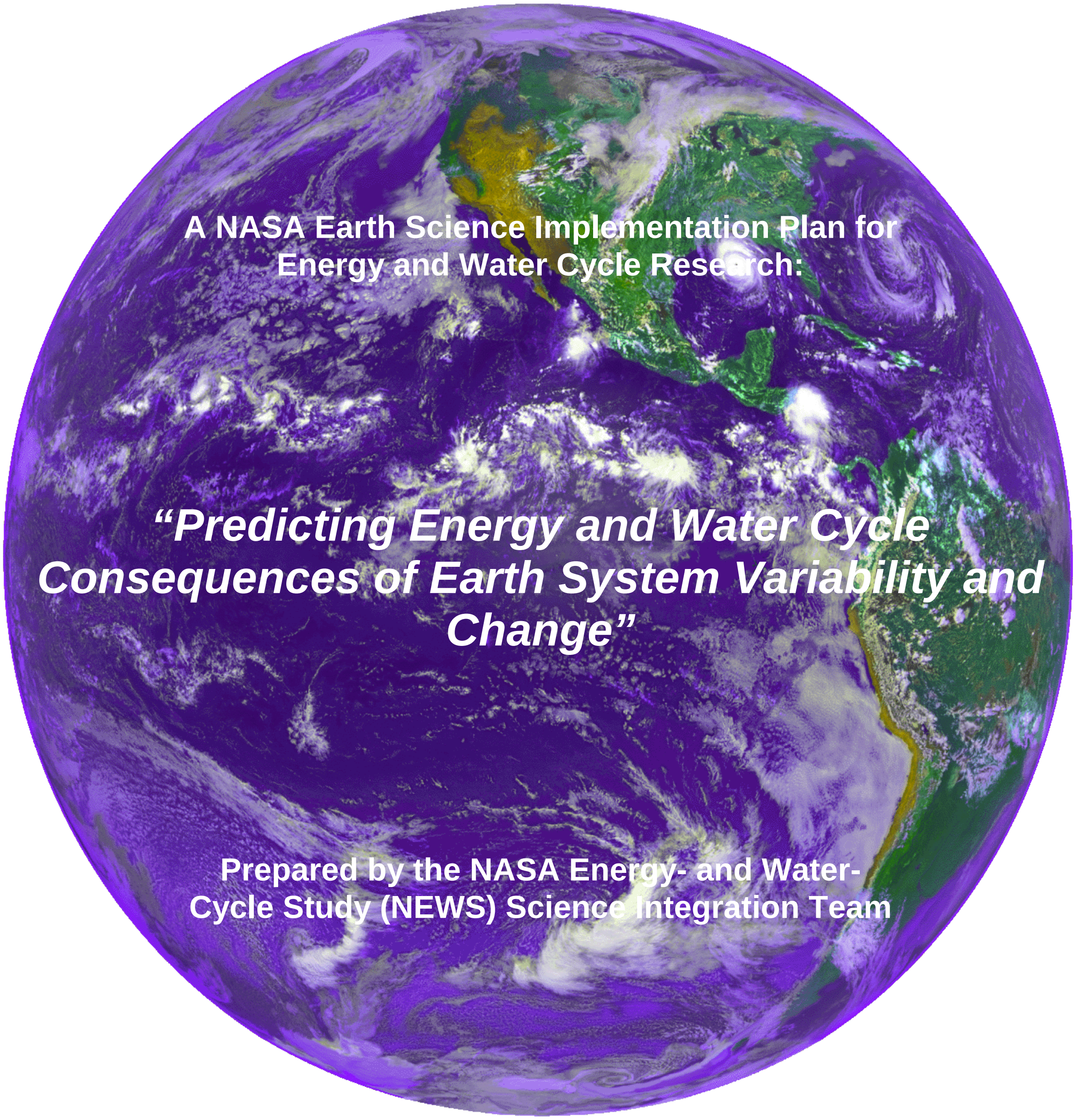

A NASA Earth Science Implementation Plan for
Energy and Water Cycle Research:

"Predicting Energy and Water Cycle Consequences of Earth System Variability and Change"

Prepared by the NASA Energy- and Water-
Cycle Study (NEWS) Science Integration Team

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Predicting Energy and Water Cycle Consequences of Earth System Variability and Change

Executive Summary

Our life on Earth is dependent on water and our economic, political and social systems will be greatly affected by alterations in the global energy and water cycle, particularly regional precipitation regimes, and extreme hydrologic events, such as floods and droughts. We know, for a fact, that climate variability and change has occurred throughout history. From an overall Earth Science perspective, the key questions are to what extent expected climate changes are related to changes in the rate of the Earth's energy and water cycles, and what trend may be predicted in the future. The energy and water cycle is driven by a multiplicity of complex processes and interactions, many of which are inadequately understood and poorly represented in climate models. Earth is the only planet in the Solar System where water exists freely in three states: liquid, vapor and sold ice. The transformations among the three states is very complex and require an understanding of moisture and energy storages and exchanges between and within the Earth's atmosphere, oceans, land, and biological systems over a wide range of space and time scales.

The scientific framework for the *Water and Energy Cycle focus area* is outlined in the NASA Earth Science Enterprise Strategy document, issued in October 2003. It is one of six focus areas that define the scientific content of the NASA Earth Science Program, and includes both research and technology components. Its implementation is planned through NEWS (NASA Energy and Water Cycle Study), a coordinated research program, whose central goal is "***to document and enable improved, observationally-based, predictions of energy and water cycle consequences of Earth system variability and change.***"

The scientific priorities adopted by NEWS reflect the issues outlined in the Strategic Plan for the U.S. Climate Change Science Program (July 2003). These are:

- To understand the mechanisms and processes responsible for the maintenance and variability of the energy and water cycle, including the extent of human interaction
- To determine how feedback processes control the interactions between the global energy and water cycle and other components of the climate system, and how these feedbacks are changing over time
- To assess the key uncertainties in seasonal-to-annual and longer term predictions of energy and water cycle variables, and to outline improvements needed in global and regional models to reduce these uncertainties
- To evaluate the consequences, over a range of space and time scales, of energy and water cycle variability and change to human societies and ecosystems, and their affect on nutrient and biogeochemical cycles
- To provide a scientific basis for supporting informed decision processes in the context of changing water resource conditions and policies

When fully implemented, the proposed NEWS research program will yield significant advances and breakthroughs in hydrological cycle climate science. Progress in achieving its objectives will be measured against its success in identifying gaps and making significant advances in:

- Promoting the development and deployment of an experimental energy and water cycle global observing system
- Assessing the global energy and water cycle through an observational record of all associated geophysical parameters
- Building a fully interactive experimental global climate model that encompasses the process-level forcings on and feedbacks within the global energy and water cycle
- Creating a global land and atmosphere data assimilation system for energy and water variables
- Assessing the variability of the global energy and water cycle on time scales ranging from seasonal to decadal, and space scales ranging from regional to continental to global
- Supporting the application of climate prediction capabilities for estimating the societal impact of climate variability and climate changes on water resources over a variety of spatial and temporal scales.

The broad national objectives of energy and water related climate research extend well beyond the purview of any single agency or program, and call for the support of many activities that are matched to each agency's respective roles and missions. NASA has the experience and expertise to support the full range of investigations, from global-remote sensing to point-scale field observations, global data acquisition, and the development of prediction systems that can assimilate these measurements. Therefore, to achieve the ultimate goal of operational global change predictions and applications across all significant scales NASA will seek collaborations with other Federal agencies, in particular the National Oceanic and Atmospheric Administration (NOAA), National Science Foundation (NSF), Department of Energy (DoE), U.S. Geological Survey (USGS), Department of the Interior (DoI), the Department of Agriculture (DoA), the scientific community-at-large and private industry. Such interagency collaborations, reflect NASA contributions to the overall Climate Change Science Program (CCSP) Global Water Cycle (GWC) initiative, and include experimental and operational observations and analysis tools for characterizing air/sea fluxes, ocean circulation, atmospheric state, land surface vegetation, sub-surface hydrology, snow and ice among others; as well as support for the development of new general circulation models and end-to-end prediction systems. In some cases, NASA investments may be required to supplement these activities to ensure that they meet specific needs, for example, *in situ* measurements of parameters that are essential to validating space based remote sensing, as well as quantities needed but not otherwise measured or derived.

The NASA /NEWS research linkage to the international science community is primarily through the World Climate Research Programme (WCRP), especially the Global Energy and Water Experiment (GEWEX), but includes several complementary elements of Climate Variability and Predictability (CLIVAR) and Climate and Cryosphere (CLIC). GEWEX has overall WCRP responsibility for providing an international interface with all the national space agencies concerning energy and water cycle related global climate research requirements, instruments, data, and science support. Other international connections include those with the International Geosphere-Biosphere Program (IGBP) and the International Human Dimensions Program (IHDP).

Implementation of the NEWS program is planned in three phases as described in Chapter 4, each successive phase being focused on a range of research activities, as described in Chapter 3 and represents advances beyond the current status of observations, modeling and applications as summarized in Chapter 2. The next-generation prediction system will be based on a global observing and assimilation system to determine the initial state of climate (especially external and internal forcings) and a modeling system to make the forecast, neither of which currently exist in complete or accurate form. Developing the prediction capability requires progressing through a iterative cycle of research elements: observations, analysis, model development and testing, evaluation, and demonstration of applications. The development of observing/data analysis system capabilities evolves in parallel with the program's research efforts to further develop prediction models and applications.

The emphasis during **Phase-1** is to exploit current capabilities and prepare for future developments of NEWS program elements. **Phase-2** focuses on addressing deficiencies and building a viable "prediction" system. **Phase-3**, focuses on the delivery of an end-to-end system to address the NASA Earth Science vision, namely: comprehensive observations to accurately quantify the state and variability of the global water cycle, including time series data sets with no major gaps; routine analysis of variability in storage, transports and fluxes of water ; routine prediction of key water cycle parameters (including clouds, precipitation, radiation interactions, energy budgets, and surface hydrological variables), and improved forecasts for use in water management and decision making.

Specifically, **the first phase** focuses on the first coordinated attempt to describe the complete global energy and water cycle using existing and forthcoming satellite and ground based observations, and laying the foundation for essential NEWS developments in model representations of atmospheric energy and water exchange processes. This comprehensive energy and water data analysis program must exploit crucial datasets, some still requiring complete re-processing, and new satellite measurements. These data products will then be evaluated for accuracy and consistency, in part by using them in the first diagnosis of the weather-scale (space and time) variations of the global energy and water cycle over the past one-two decades**.** The primary objective is to ensure that results of this analysis effort serve as a recognized data basis to compare with corresponding climate statistics produced by existing climate models, quantify systematic deficiencies, and identify needed improvements. The data records to be produced through these efforts are mandatory for developing and validating models that meet NEWS scientific requirements.

The second phase will focus on correcting the deficiencies identified in the first phase, exploiting and evaluating the newer measurements from recently deployed satellites (especially GPM), advancing multivariate analysis procedures to exploit the full range of observations, and developing new measurement approaches for future flight missions. Simultaneously, the second phase includes implementing new process-resolving or otherwise improved representations of energy and water exchange processes in general circulation models (GCM), assembling a complete end-to-end data assimilation and prediction system for seasonal and shorter-range forecasts, and testing the predictions against observed transient variations or changes in climate statistics. This will involve reprocessing of legacy data as required. An important objective of the second phase is to deliver useful seasonal predictions that can be applied to, and evaluated for their value to optimize water management decision-making.

The third phase will focus on facilitating the development of a capability for short term, and annual to decadal-scale climate predictions, in cooperation with the climate modeling community. The implementation plan calls for delivery of advanced atmospheric GCM formulations that can demonstrably predict changes in the energy and water cycle up to at least several seasons. An objective of the third phase will be testing against observations decadal predictions produced by fully interactive models of the complete climate system and/or simpler configurations involving the partial replacement of active components by observed boundary conditions. The third phase will also aim to deliver more penetrating tests of model performances using extended analyses of the widest possible range of observations, including some of the new global observing systems evaluated in the second phase.

It is envisioned that the NEWS program will build upon existing NASA-supported basic research in atmospheric physics and dynamics, radiation, climate modeling, and terrestrial hydrology. While these NASA programs fund research activities that address individual aspects of the global energy and water cycles, they are not specifically designed to generate a coordinated result. The implementation concept for NEWS is specifically intended to promote innovative mechanisms to work across these programmatic boundaries.

The NEWS activity will be comprised principally of product-driven investigations, exploration-driven investigations and integrative efforts studies. NEWS will include:

- Product-Driven Investigations: Systematic research investigations intended to combine and interpret past and current observations, derive global analysis and prediction tools and products and identify technological and observational requirements to guide future NASA investments.
- Discovery-Driven Investigations: Fundamental investigations to identify key missing elements and explore new scientific frontiers to improve capabilities and knowledge of the energy and water components of the Earth system..
- NEWS Science Integration Team: Integration of the science activities to serve the overall purpose of NASA by acting as an interface with other Earth Science research foci and activities, coordinating the conduct of NEWS investigations, and leading specific studies needed for integration of the results of independent product-driven or discovery-driven investigations.

Exchanges of energy and water within the Earth system involve a multiplicity of interactive processes. Understanding and predicting these processes require a complex multi-disciplinary research program, innovative observing tools, and advanced model developments. Organizing these complex activities calls for dedicated management and oversight approaches to ensure that both financial and human resources are efficiently applied to serve NASA Earth Science priorities.

1 Program Overview

The NASA Earth Science mission is to understand and protect our home planet by using our view from space to study the Earth system and improve predictions of Earth system change. NASA, working with its domestic and international partners, provides accurate, objective scientific data and analyses to advance our understanding of Earth system processes and to help policy makers and citizens achieve both economic growth and effective stewardship of Earth's resources. NASA's research program aims to acquire deeper scientific understanding of the components of the Earth system, their interactions, and the consequences of changes in the Earth system for life. These interactions occur on a continuum of temporal and spatial scales ranging from short-term weather to long-term climate and motions of the solid Earth, and from local and regional to global scale.

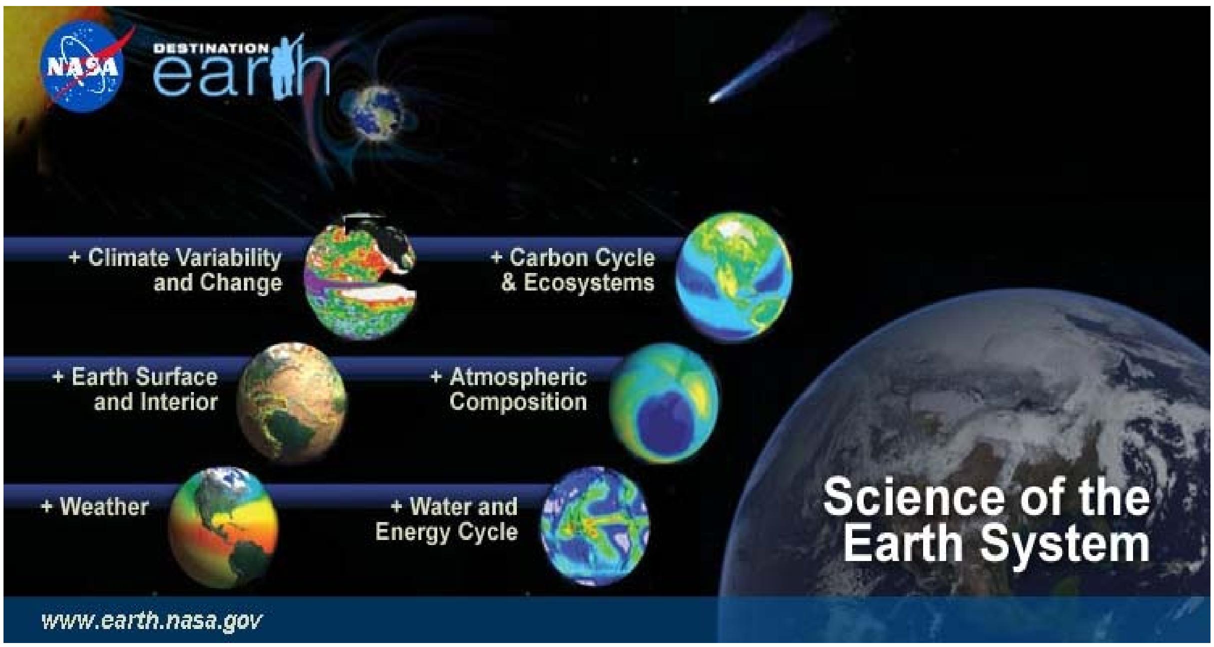

Figure 1.0: The Water and Energy Cycle is one of six focus areas that define the scientific content of the NASA Earth Science program

Three research thrusts represent the frontier of current knowledge, for example: (1) explore interactions among the major components of the Earth system – continents, oceans, atmosphere, ice, and life, (2) distinguish natural from human-induced causes of change, and (3) understand and predict the consequences of change. NASA has established six research focus areas for the study of these complex processes (Figure 1.0). These focus areas are: Atmospheric Composition, Carbon Cycle and Ecosystems, Climate Variability and Change, Earth Surface and Interior, Water and Energy Cycle, and Weather. This implementation plan establishes a methodology to help NASA answer, either in full or in part, the second-tier research questions related to the Water and Energy Cycle focus area: The questions are:

- How are global precipitation, evaporation and the cycling of water changing?
- What are the effects of clouds and surface hydrologic processes on Earth's climate?

- How are variations in local weather, precipitation and water resources related to global climate variation?
- What are the consequences of land cover and land use change for human societies and the sustainability of ecosystems?
- What are the consequences of climate change and increased human activities for coastal regions?
- How can weather forecast duration and reliability be improved?
- How can predictions of climate variability and change be improved?
- How will water cycle dynamics change in the future?

The overarching long-term challenge of the ESE Water and Energy Cycle focus area is summarized as: ***documenting and enabling improved, observation-based predictions of the water and energy cycle consequences of Earth system variability and change***. The roadmap (Figure 1.1) for this research focus area provides the conceptual framework for research that will be organized and implemented by the *NASA Energy and Water cycle Study (NEWS)*. This and other ESE research focus areas are interrelated and must be integrated eventually to construct a fully interactive representation of the Earth system.

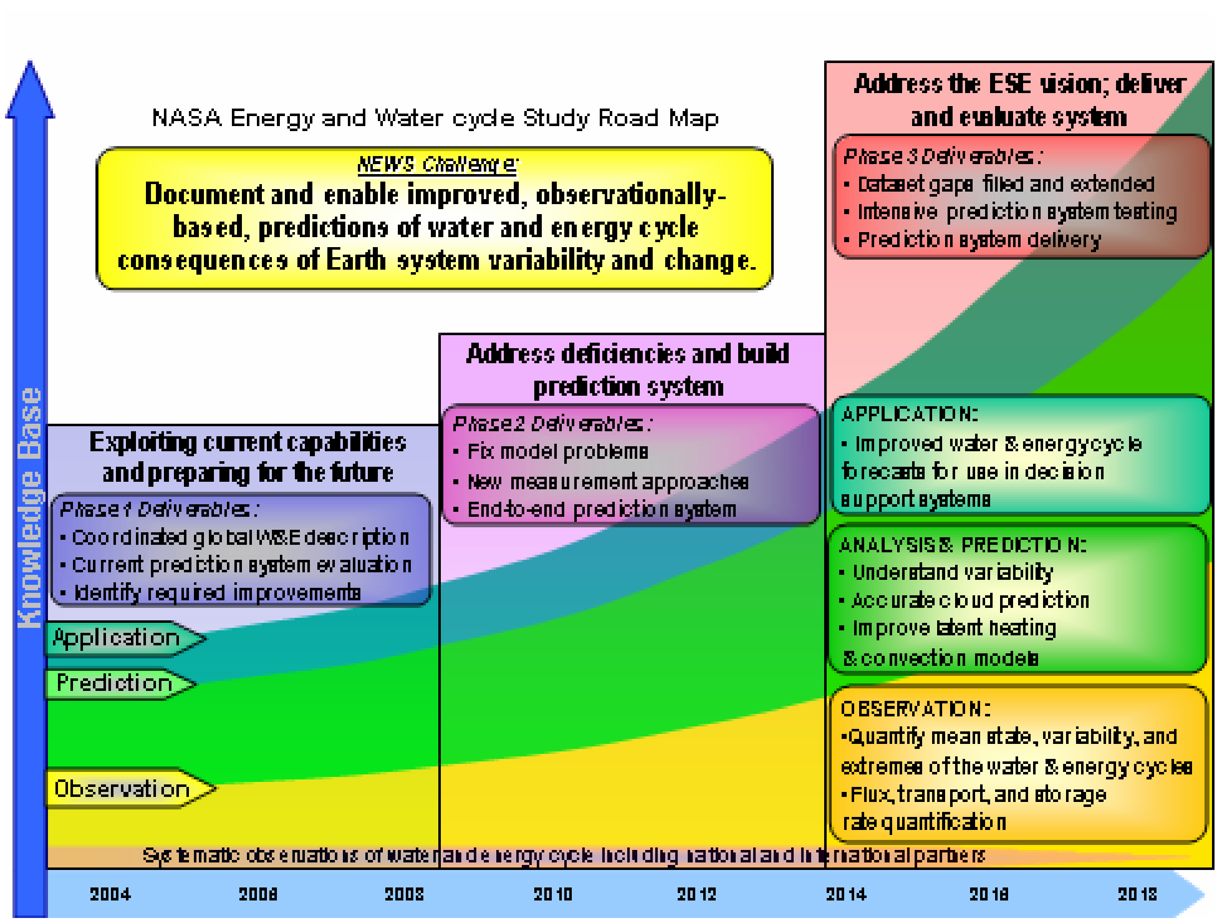

Figure 1.1: NASA Energy and Water cycle Study Road Map

This implementation plan also responds to the national scientific priorities identified by the US Climate Change Science Program (CCSP), encompassing the Climate Change Research Initiative (CCRI) and the US Global Change Research Program (USGCRP), and to international scientific priorities identified by the World Climate Research Programme (WCRP), the Committee on Earth Observation Satellites (CEOS), the Global Climate Observing System (GCOS), the Integrated Global Observing Strategy (IGOS) and the framework and implementation plan for the creation of a Global Earth Observing System of Systems (GEOSS) following the first Earth Observation Summit held July 2003 in Washington D.C. and successive summits in Tokyo and Brussels in 2004. The goal of these programs is to lay the scientific basis for the development of public policy and natural resource management tools related to climate change.

1.1 Scientific Scope

The Earth's unique capability to sustain life is due to the abundance and vigorous cycling of water through the global environment. The global water cycle consists in the transport and transformation of water within the Earth system, and the distribution of fresh water over the Earth’s surface. This cycling occurs on a wide spectrum of time and space scales, from cloud microphysics to global redistribution. The water cycle also represents exchanges of large amounts of energy, as water undergoes thermodynamic phase changes and long-range transport from one part of the Earth system to another. Because both the radiative effects of cloudiness and the release of latent heat are intimately linked to weather system dynamics and water condensation processes, the study of the energy cycle is inescapably entwined with the study of the water cycle. While the global water cycle drives the hydrologic consequences of climate changes, it is both a consequence and a driving factor of the global energy cycle.

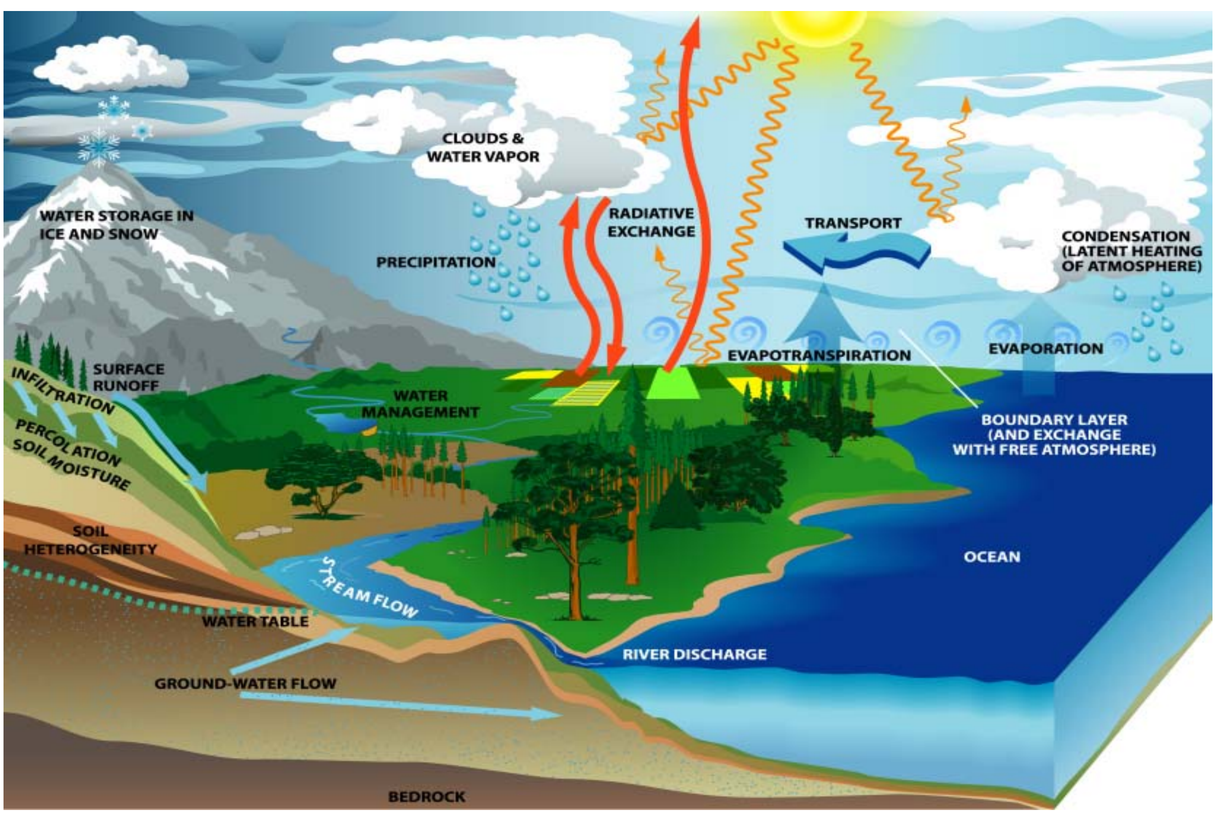

Figure 1.2: Conceptualization of the Energy and Water Cycle

Natural and human-induced changes to the energy and water cycle have major consequences for industry, agriculture, and other human activities. The increased density and exposure of human settlements in flood plains and coastal regions amplify the potential loss of life, property, and commodities that are at risk from intense precipitation events. However, current projections of such impacts will remain speculative until scientific understanding of climate change is validated against observed events and assimilated into reliable global predictions and effective decision support tools applicable to local conditions. Predicting the hydrologic consequences of global change - whether natural or human-induced - and developing practical applications of climate, weather, and hydrologic forecasts are the ultimate challenges of NEWS and the ESE Research Strategy in general.

1.2 Overarching NEWS Goals and Research Priorities

One of the most important manifestations of change in the Earth's climate would be change in the global water cycle including regional precipitation regimes, increased evaporation and the exacerbation of extreme hydrologic events, such as floods and droughts. From an overall Earth Science perspective, the key questions are whether the expected climate changes (e.g. warming) entail changes in the rate of the Earth's water cycle and what trend may be expected in the future.

While climate research, in general, aims to understand climate processes and predict changes in the state of the climate system, NEWS will investigate temperature/moisture gradients and localized energy/water sources or sinks (flux divergence) that drive weather dynamics, global water transport and hydrologic extremes. It is envisioned that accurate estimations of key energy and water reservoirs and fluxes, including space-time variability and extreme events, will lead to more accurate model representations of energy and water processes and thereby contribute essential new tools for the advancement of climate change science and predictions.

The ultimate goal of NEWS is a breakthrough improvement in the nation's energy and water cycle prediction capability. NEWS is expected to demonstrate advanced global observation, data assimilation, improved representation of physical processes in climate model and better prediction systems that can be used to quantify the hydrologic consequences of climate change and produce useful seasonal and longer-range hydrologic predictions based on observed initial values and changing boundary conditions.

1.3 NASA Guidelines

The guidelines for the implementation of the NASA Energy and Water cycle Study result from NASA's overall mission and unique capabilities. The following considerations apply:

- The NASA Earth Science Program addresses energy and water cycle science issues that are *global in scope*. Predictions of energy and water cycle consequences of climate variability and change require understanding multiple-scale teleconnections and feedback processes. NASA supports related basic research, especially process-resolving modeling or laboratory studies, and invests in field campaigns, primarily as a means to enhance the scientific investigations of global phenomena identified by space-based observation.
- NASA currently has substantial energy and water cycle data archives and assets that need to be *integrated* and reanalyzed to make new scientific advances. In addition, NASA maintains a substantial investment in discovery-driven scientific research as well as the development of related technological innovations.

- NASA is a research-and-development agency. While its mission includes supporting research that can enable improvements in operational monitoring, prediction and water resources management, NASA does not itself manage water systems, nor provide operational inputs to such applications. Nonetheless, it is envisioned that NASA efforts will contribute towards national goals for water cycle prediction; especially in developing, testing, and implementing the means to exploit new environmental information delivered by NASA's research programs.
- NASA's unique vocation is to produce key scientific inputs using global observations from space and to exploit these data for Earth system monitoring and for the initialization and validation of global environmental predictions (Figure 1.3). NASA has the capability to support the full range of investigations, from global-remote sensing to point-scale field observations, global data acquisition, and the development of prediction systems that can assimilate these measurements. However, NASA alone cannot achieve the ultimate goal of operational predictions and applications and seeks collaborations with other agencies, the scientific community-at-large and private industry.

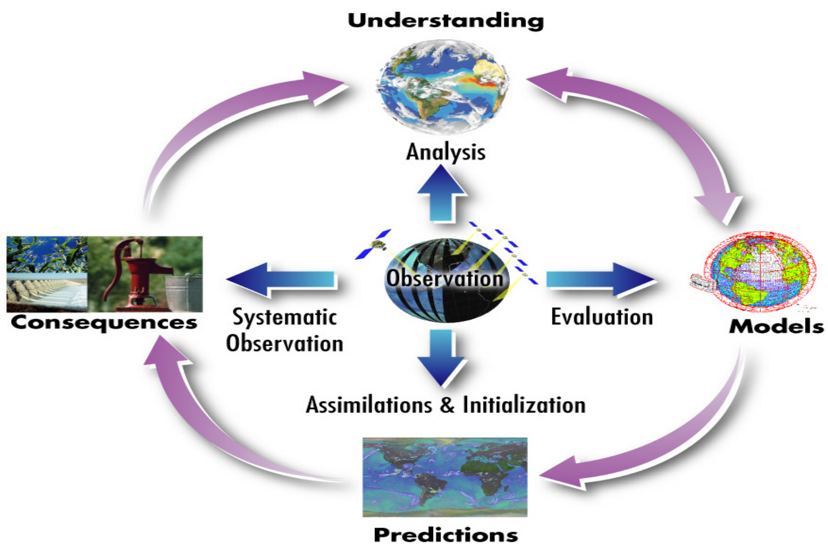

Figure 1.3: NASA's End to End Research Strategy

Given these premises, this implementation plan describes the anticipated activities, from the acquisition and analysis of global observations to data assimilation and model development that will yield new understanding of the global energy and water cycles, leading to improved prediction systems and innovative applications to water management.

1.4 Implementation Overview

Consistent with the ambitious NEWS challenge and Earth Science objectives, the timetable for the implementation of NEWS extends over a 15- year period. During this period, NEWS participants are expected to collect, analyze and interpret observational data from archived records and on-going observing systems, contribute to the preparation of new space-flight missions, advance predictive models of the global energy and water cycle, and lay the foundation for future developments (including potential new observing techniques). NEWS participants are also expected to examine and test new application practices in partnership with relevant operational agencies and industry.

The implementation of NEWS is planned in three phases as described in Chapter 4, each successive phase being focused on a range of research activities previously described in Chapter 3. It is envisioned that NEWS will build upon existing NASA-supported basic research in atmospheric physics and dynamics, climate modeling, and terrestrial hydrology. While these NASA programs fund research activities that address individual aspects of the global energy and water cycle, they are not designed to generate a coordinated result nor synergistic cooperation between NASA scientists and the scientific community at large. The implementation concept for NEWS is specifically intended to work across these programmatic boundaries.

The cycling of energy and water has obvious and significant implications for the health and prosperity of society. NEWS is envisioned to be part of the broader NASA end-to-end Earth science program. The overall program thus includes the transition of research findings and new capabilities to academic/public education and to practical applications, through partnerships with the academic community-at-large, federal agencies that oversee environmental protection and operational applications, and eventually private sector operators.

While the NEWS research program is expected to yield incremental advances and breakthroughs over an extended period of time, progress in achieving its long-term objectives will be measured against its success in making significant contributions to:

- Development and deployment of an experimental integrated energy and water cycle global observing system
- Documenting the global energy and water cycle through obtaining a complete observational record of all associated geophysical parameters
- Building a fully interactive global climate model that encompasses the process-level forcings on and feedbacks within the global energy and water cycle
- Creating a global land and atmosphere data assimilation system for energy and water variables
- Assessing the variability of the global energy and water cycle on time scales ranging from seasonal to decadal, and space scales ranging from regional to continental to global
- Supporting the application of climate prediction capabilities for estimating the impact of climate variability and climate changes on water resources **over a variety of spatial and temporal scales**
- The breadth of these challenges demands international, multi-agency contributions. As detailed in section 5.0 NEWS will partner and contribute as appropriate to facilitate and enable these advances.

1.5 Scientific Organization and Oversight

NASA investments in Earth science research have resulted in the acquisition of global observation capabilities, data resources, and scientific expertise that must now be integrated to address the NEWS challenges. To this effect, the NEWS activity will be comprised principally of NEWS discovery-driven investigations, product-driven investigations, and integration studies, but it will also be open to any relevant energy and water cycle investigation. NEWS will include:

- <u>Product-Driven Investigations</u>: Systematic research investigations intended to combine and interpret past and current observations, derive global analysis and prediction tools and products and identify technological and observational requirements to guide future NASA investments.

- Discovery-Driven Investigations: Fundamental investigations to identify key missing elements and explore new scientific frontiers topic to improve capabilities and knowledge of the energy and water components of the Earth system.
- NEWS Science Integration Team: Integration of the science activities to serve the overall purpose of NASA by acting as an interface with other NASA research foci and activities, coordinating the conduct of NEWS investigations, and leading specific studies needed for integration of the results of independent product-driven or discovery-driven investigations.

1.6 Planning Flexibility

As progress is made and lessons are learned, it is envisioned that NEWS results will be widely available and evaluated by the scientific community. The NEWS Science Integration Team will periodically review and revise the NEWS Implementation Plan in the light of the broad community response to the scientific outcome of NEWS.

2 Current Capabilities and Development Objectives

2.1 Current Observational Resources, Capabilities and Examples of Deficiencies

Over the last decade satellites have proven the capability to accurately monitor many aspects of the total Earth system on a global scale. This is a capability unmatched by surface based systems which are generally limited to land areas covering only about 30% of the planetary surface and concentrated in the northern hemisphere. Currently, satellite systems monitor the evolution and impacts of El Nino, weather phenomena (particularly atmospheric moisture and temperature as well as clouds and precipitation), natural hazards and extreme events such as floods and droughts, vegetation cycles, the ozone hole, solar fluctuations, changes in snow cover, sea ice and ice sheets, ocean surface temperatures, surface winds and biological activity, coastal zones and algae blooms, deforestation, forest fires, urban development, volcanic activity, tectonic plate motions, and others. These observations are used extensively in real-time decision making and for strategic planning and management of industrial, economic, and natural resources. Examples include weather and climate forecasting, agriculture, transportation, energy and water resources management, urban planning, forestry, fisheries, and early warning systems for natural disasters and human health impacts. Among the most significant outstanding gaps are global observations of land surface hydrology parameters such as soil moisture and ground water storage, soil freezing and thawing, surface water reservoirs and river discharge. Also needed are surface-based, and in-situ observations for determining geophysical variables that cannot directly be measured from space and for the calibration and validation of long-term records of satellite-derived geophysical, chemical and biological quantities.

Historically, the majority of operational space-based observations were disparate, not well-calibrated nor uniformly processed, and do not lend themselves to assembling a consistent long-term record of global scale phenomena. Notable exceptions have been inter-calibration efforts with the Microwave Sounding Unit (MSU) tropospheric temperatures and SSM/I water vapor and winds Further, several more recent efforts have been directed at re-processing long-term records of operational satellite data using new retrieval algorithms developed for space-based research observations. Examples include the derivation of time series of precipitation estimates by applying TRMM retrieval algorithms to historical SSM/I microwave observations. While these efforts have shown great promise in the usage of multi-satellite information, they fall short to providing a globally comprehensive water and energy cycle long-term observation record.

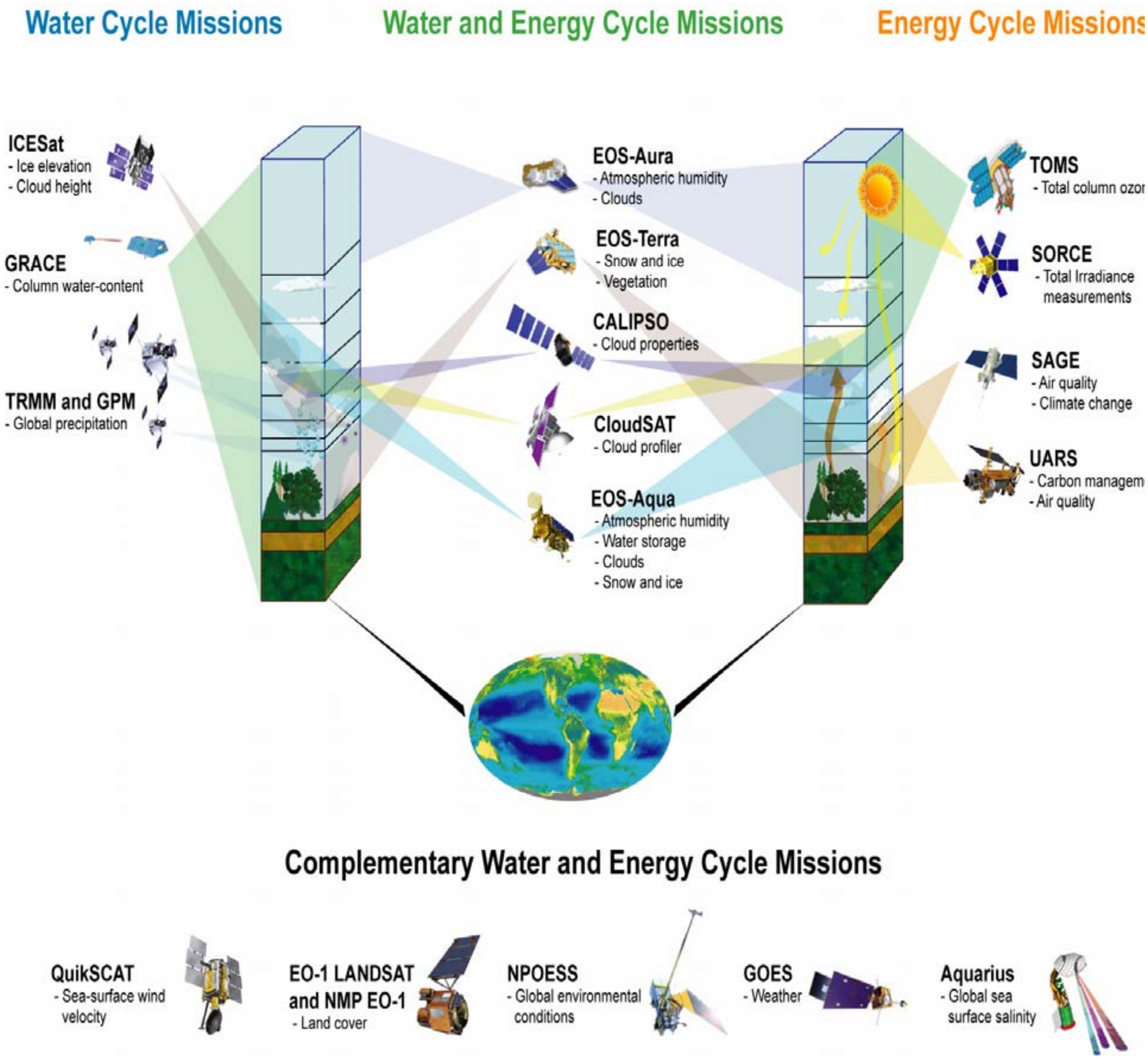

Figure 2.1: *Satellite Missions to Observe the Global Energy and Water Cycle*

In terms of the more recent, current and pending missions (Figure 2.1), the orbiting fleet of eighteen NASA research satellites providing relevant energy and water-cycle observations include: the TRMM precipitation measurement satellite and the Global Precipitation Measurement (GPM) constellation; the EOS Terra, Aqua and Aura satellites that pave the way to the next-generation NPOESS operational satellites; the GRACE Earth gravity measurement mission; the ICESat global topography mission; Landsat and EO-1 Earth surface imaging; QuikSCAT ocean surface wind measurements; CloudSAT and Calipso to measure the horizontal and vertical structure of cloud, snowfall and aerosol optical properties; SORCE satellite to observe solar radiation, and the other relevant energy and water-cycle missions (i.e. TOPEX-POSIDEON, JASON, QuikSCAT, EO-1, NPOESS, GOES, Aquarius, etc.) further illustrated in Figure 2.2, and detailed on the NASA/ESE website (www.earth.nasa.gov).

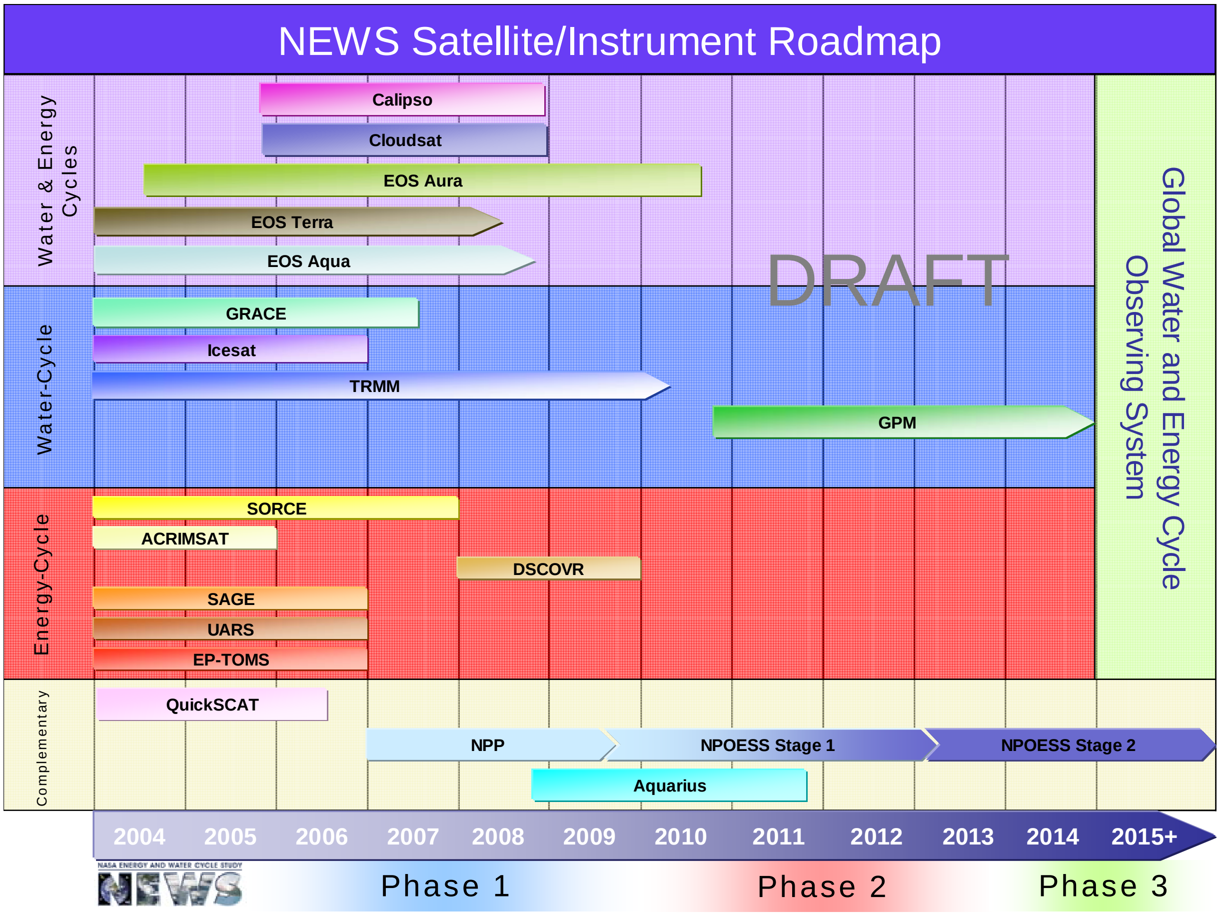

Figure 2.2 *Timeline of Energy and Water Cycle Observations from Satellite Missions*

These experimental/research satellites are typically aimed at measuring specific components and/or processes of the global energy and water cycles, over a relatively short period of time – in a climatological perspective. While measurement systems scheduled for the near future will fill in critical observational gaps or improve current observational capabilities, only incomplete provisions are being made for high quality measurements of some essential climate variables; notably ocean surface winds. This may require collecting data from an ad-hoc succession of diverse satellite measurements and appropriate data analysis methods to ensure long-term consistency. Inferring reliable climatological records of variables and trends in the global energy and water cycle from multiple space and surface based observing systems remains a research challenge, even for basic quantities such as rainfall. Thus, a substantial long-term effort is required to periodically reanalyze the complete collection of satellite data with improved retrieval algorithms, and to develop the means for satellite sensor inter-calibrations. A recent WCRP Report on Satellites Observations calls for the following action: "*Space agencies should consider an international effort in order to meet the GCOS and WCRP needs for cross-calibration, overlap, and continuity for operational satellites. Meeting these objectives within budgetary constraints will likely require innovative approaches. Such approaches may wish to consider a cooperative mission using a subset of common passive frequencies in the visible, infrared, and microwave spectrum and optimum orbital configuration to serve as a common radiance transfer standard.*"

2.2 Current Modeling Resources, Predictive Capabilities and Examples of Deficiencies

There are various types of numerical models for land, atmosphere and ocean that can be applied to simulate the water and energy cycles of the Earth system across the range of spatial and temporal scales required. Radiative transfer models are required to simulate the impact of clouds and aerosols on the energy budget. Nonhydrostatic cloud resolving models (CRM's) are used to simulate cloud microphysical processes important to precipitating systems and the energy budget. Nonhydrostatic limited area mesoscale models such as the Weather Research and Forecast (WRF) model can be applied across a range of spatial scales to explicitly simulate convection or capture the entire structure of individual synoptic scale baroclinic systems. Global models are currently run operationally at spatial scales of 25 km are capable of producing skillful predictions of planetary and synoptic scale wave structures out to 10 days. Global climate models (GCM's) are run in research mode to simulate past and future climate at resolutions approaching 150 km. It is important to note that in some cases the above mentioned systems may be composed of interactive land, atmosphere and oceanic components. The challenge to the scientific community and one that NEWS needs to address is the ability to integrate and dynamically couple component systems into a coherent modeling system capable of providing realistic simulations of energy and water cycle variables.

Most current GCM's are suited for estimating first-order changes in atmospheric temperature profiles, (and thus surface temperature) in response to changes in radiant energy transfer or radiative forcing caused by various factors, such as changes in the concentration of greenhouse gases, anthropogenic aerosols, surface albedo, or the solar constant. Assessments of climate change, notably those conducted by the Intergovernmental panel on Climate Change (IPCC), focus almost exclusively on ground and near surface air temperature variations and trends. Existing climate models are notoriously challenged with regards to reproducing and predicting changes in atmospheric moist processes such as clouds and associated precipitation systems. Future model development must lead to a reliable capability to prescribe the extent to which variations in the global climate induce predictable changes in the frequency, intensity, and geographical distribution of weather systems.

There is a substantial thrust towards increasing model resolution to better capture sub-grid scale processes such as cloud formation and the spatial and temporal variability of simulated precipitation. Most global models applied to climate change studies are operated at horizontal resolutions near 200 km. Operational centers run global models below 100 km resolution for the purpose of medium range weather forecasting and even research-based global systems have been operated quasi-operationally at resolution approaching 25 km during the Atlantic hurricane season. Short-range (0-3 day) operational modeling systems are currently at 8 km resolution in deterministic mode. Application of numerical modeling systems at spatial resolutions (below 10 km) necessary to begin explicit representation of processes important to the energy and water requires non-hydrostatic dynamics. Several theoretical assumptions (regarding process parameterizations) that were/are applied to the larger-scale resolutions will not apply at small spatial resolution and will need to be adjusted accordingly or discarded completely.

Recent modeling studies have identified problems with the representation of the atmospheric boundary layer, moisture transport, and land surface/hydrology parameterization. Differences in the parameterizations of these components or processes within a model, or between models, lead to disagreement in the resulting large scale atmospheric circulation and thermodynamics. Uncertain or unknown parameterization of cloud formation processes (including aerosol interactions) are known to strongly influence precipitation as well as radiation feedback, all leading to regional (particularly) and global variances in model-computed water resources.

Representation of moist processes in numerical models must be improved in order to reduce uncertainties in simulations of the water and energy cycles and associated budgets.

Model simulation/prediction exercises demonstrate the stochastic/dynamic nature of the atmosphere-land-ocean system is perhaps best represented by ensemble integrations. Ensemble integrations are routinely performed for weather forecasting and are gaining popularity in other areas such as hydrological forecasting of river flow and water resources. To a degree "ensemble" integrations are also applied implicitly in climate change projections based on the results of different participating centers around the world. For predictions on the seasonal to interannual time scales "super-ensemble" prediction techniques hold considerable promise as "super-parameterization." The Super-ensemble approach_evaluates the performance of each model within a suite of models (e.g., those used for AMIP and CMIP intercomparison studies) for regional prediction skills (e.g., precipitation) by comparison to observations (typically re-analysis fields and various precipitation and other products). These so-called training runs over certain specified time periods (based on the available observational time series available) are used to compute spatially differentiated "weights" for the individual model predictions. These weights are then used in the forward prediction integration of the same suite/ensemble of models. The super-parameterization approach provides a measure of feedback between sub-grid-scale processes (via high resolution cloud models run at a sub-sampled spatial scale) to a global model of lower space/time resolution. In the near term these ensemble methodologies appear to be the best avenues to improve seasonal to interannual prediction skills. It is to be noted that “superparameterization has not been tested for seasonal-interannual prediction, but the concept conceivably applies to this time scale as well. They could be applied to coupled climate models as well for climate change projections not yet tested. On the longer term, the fundamentals of global models (be they atmospheric or coupled) need to be improved (dynamics, physics, parameterizations etc.). Such a challenging task will require a better understanding of microphysical processes via observational experiments and modeling studies. NEWS will begin to address this issue along with efforts to improve prediction skills of water/energy cycle parameters on the short term in order to facilitate the delivery of applications products for water resource management (as an example) among others.

Terrestrial hydrological models are typically designed to run on a catchement or basin scale. Linking these models with atmospheric models integrated at much larger scales continues to pose problems. Atmospheric and hydrological models possess widely differing levels of complexity which attempt to partition the surface rainfall input (observed or modeled) into runoff, infiltration, percolation, etc. Some include lateral transport of water. Some employ one-dimensional water budget accounting schemes, while others incorporate complex dynamics and lateral coupling. They all require surface observations or model derived inputs for flux computations and initialization. Improvements, therefore, in hydrological model predictions, on any time scale, depend upon considerably better observations of the atmosphere-land-vegetation interface and the representation of these processes in models. Recent studies indicate that even on “weather’ time scales, atmosphere-land surface-vegetation-ocean coupled models produce significant improvements.

Models hold considerable promise for full environmental prediction, but the limits to such prediction have yet to be fully established. Furthermore, collecting the data necessary to evaluate model results presents its own challenges. Models produce numerous fields of physical variables, all of which could or should be evaluated against observations. But, most often, uncertainties resulting from either model deficiencies or observational data cannot be resolved. To address these problems, it is customary to carry out focused field campaigns or field experiments with enhanced observations over limited domains to research one or more process or hypothesis.

Except at the most basic stage of model formulation, such space and time limited intensive field studies cannot be generalized, either because they do not define mean field and boundary conditions completely enough or because the models to be evaluated cannot ingest the information. Thus, there is a concurrent need for accurate long time series of observational fields and for model simulation/prediction experiments aimed at improving the representation (parameterization) or simulation (prediction) on time scales ranging from hours/days (hazard warnings) to week and months/seasons (for resource management), or longer (for determining the impacts of global climate change).

Although a wealth of satellite data has become available in recent years, not all models are positioned to use it, due to the simplicity of the parameterizations employed and/or because the data must still be transformed into geophysical quantities that are appropriate for the model. Data assimilation systems are largely designed to use these data, but data assimilation presents its own challenges. Furthermore, model error propagation, needed for assigning assimilation weights, is not quantitatively known. The overall implication is that both our observed and theoretical bases of climate predictability are still in question.

2.3 Current Applications Deficiencies

Applications of energy and water cycle research are extensive in scope, yet few of the methodologies can said to be mature. Short-term weather and flood forecasting (hazard warning) and hydrologic predictions for water resource management, including impact of El-Nino/La Nino cycles and global climate change are familiar examples. Early warnings of weather hazards are routinely delivered to mitigate the impact of severe weather on transportation (land and shipping), agriculture, and other application sectors that require decisions to be made on these time scales. The management of water resources on a daily to monthly time period requires water cycle variables to be measured to hourly intervals to support such practices as irrigation management and flood forecasting. Conversely, the management of resources on an annual basis requires the delivery of projections or predictions of water cycle variables on a month to seasonal to inter-annual time scale, for it to be effective or usable. Economic and infrastructure development sectors require the delivery of future predictions/projections of Earth/climate system variations and change on time scales ranging from decades to centuries, in particular, building new infrastructures (e.g., dams, hydro-power etc., agricultural development, land use and urban expansion etc.) requires environmental projections on the long-term time horizon, partly because such projects take 10, 20, or more years to design, build and implement.

Examples of recently developed applications of current scientific understanding include:

- A joint NOAA/NASA GAPP funded project on improving water demand analysis and prediction for water managers is designed to improve the estimates of evapotranspiration over the Middle Rio Grande Basin in New Mexico from just above Cochiti Reservoir southward to Elephant Butte Dam. It uses satellite, radar, surface observations and numerical forecasts with land surface modeling to integrate Land Data Assimilation System information into water operations decision support systems displayed on the web. Reclamation's water managers and their stakeholders in water conservancy districts and farmers may access the information daily to conserve extremely limited resources
- A 51 year (1948-1998) reanalysis of the U.S. land-surface hydrology has been completed by NOAA/NCEP (GEWEX/GCIP/GAPP) using the NOAA land model which is also used in the NOAA/NASA North American Land Data Assimilation System (NLDAS). The VIC, Mosaic and Sacramento models are also incorporated in NLDAS. The reanalysis defines surface

climate, including inter annual variability, and places extreme events in a historical context to aid forecast applications at NCEP/CPC.

- A joint NOAA/NASA project on improving water demand analysis and prediction for U.S. Bureau of Reclamation water managers is designed to improve estimates of evapotranspiration (loss of water from the soil) in New Mexico. The project uses satellite remote sensing, radar, and surface-based observations, and numerical forecasts and surface modeling, to integrate Land Data Assimilation System (LDAS) information into water operations decision support systems, and displays decision data on the Web. Bureau of Reclamation water managers, water conservancy districts, and farmers may access the information daily to help them conserve the state's extremely limited water resources.
- An experimental on-line decision support tool designed to provide users with a description of streamflow conditions and their accompanying probabilities in the Pacific Northwest, from near-term climate predictions and long-term projections, is being developed, demonstrated and deployed in the Columbia River Basin. Data assimilation systems and land surface models developed by NASA, NOAA, and other agencies and universities will be integrated with river system management decision support systems developed by the Bureau of Reclamation and used by water managers to make daily to seasonal water operations decisions.

Clearly, the investment in NEWS along with other national and international activities will provide significant reductions in the water and energy balance errors where in many regional to global areas we are not even within 50% of closing the water balance. Significant improvements will enable water managers and policy makers for improved decisions. For example, there is an alarming world-wide decline in stream gauges leading to worsening of water and energy budget errors. This leads to practical problems such as water management practices of planning and scheduling irrigation practices, flood planning, hydropower use, and fisheries. A potential NASA Surface Water Mission and other activities (e.g., improved precipitation and hydrological distributed modeling) should improve measurements and compensate for the decline in gauged basins. Other deficiencies that NEWS work will significantly reduce include the difficulties associated with estimating soil moisture and terrestrial water storage (i.e., GRACE and a Surface Water Mission), and snowpack amount and distribution (Cold Land Process Mission). However, the largest uncertainty to the water budget will be addressed by GPM that will provide significant improvements in spatial and temporal resolution of precipitation processes. Currently, regional to global precipitation errors are significant depending on the location (e.g.'s mountains, coastal areas, oceanic, etc.) and process (e.g.'s, coastal, snowfall, mountainous, etc.). Another water and energy flux difficult to measure via remote sensing is evapotranspiration or latent heat flux. Typically, latent heat flux (or evapotranspiration) is solved as a residual to the energy balance or directly with numerous assumptions. As indicated above, the error in closing the water budget from all of the uncertainties over various temporal and spatial scales often exceeds the amount to make intelligent water management decisions. A high goal of NEWS is to reduce the errors through remote sensing and modeling that are associated with water flux measurements from regional to global areas that will provide the quality measurements useful for many water resources applications. See Section 3.3 for possible application benefits from NEWS.

3 Key Energy and Water Cycle Research Challenges

The Earth's energy and water cycle is driven by a multiplicity of complex processes and interactions, many of which are poorly understood. Its characterization requires an understanding of moisture and energy exchanges among the Earth's atmosphere, ocean and land, and biological systems over a wide range of space and time scales. The difficulty is exacerbated by the fact that water can exist on Earth in any of its three phases. NEWS planning is focused on selected aspects of the energy and water cycle that reflect the science and technology interests and capabilities of NASA. The following sections briefly outline the key components and tools that will be emphasized by NEWS research.

3.1 Key Components of the Global Energy and Water Cycle

Cloud, Radiation, and Precipitation Processes

It can be argued that the transport and condensation of water vapor are at the core of global atmospheric dynamics and climate change. Indeed the greenhouse effect of water vapor by far dominates the other components of the earth radiation balance. The maximum water-carrying capacity of the atmosphere is constrained by the Clausius-Clapeyron relationship but a crucial additional factor is the effect of atmospheric dynamics and physics that maintains the global mean relative humidity around 75% at the surface. Given an effectively infinite source of water at the ocean surface, it is likely that weather-induced atmospheric motions (that bring moist air parcels to saturation) and condensation processes control the amount and cycling rate of water in the planetary atmosphere. Those condensation processes in turn feed back into the large scale dynamics through latent heat release and the radiative effects of clouds.

Weather systems and indeed the general circulation itself are fueled by radiant energy and latent heat released by the condensation of atmospheric water vapor. Both the extent and optical properties of water and ice clouds (which control radiation fluxes) and precipitation are governed by cloud system dynamics and microphysics. Because cloud processes occur on characteristic scales of micrometers to kilometers - much smaller than the scales usually resolved by general circulation and even mesoscale models - climate models so far have not accounted for cloud processes in a realistic manner. Deficient representation of cloud amount and optical properties is generally recognized as the principal cause of error in model computations of energy and water fluxes, and a major source of uncertainty in climate model projections.

Advancing the knowledge of cloud systems and the role of clouds in global climate poses major scientific and technical challenges. Improved microphysical models are required to address the formation and growth of cloud particles in diverse saturated environments produced by atmospheric motions. This problem is especially acute for ice phase clouds. Important related issues to be considered include the role of aerosols as condensation nuclei and cloud particle freezing-melting processes. The goal of NEWS is to develop and exploit comprehensive Process-Resolving Cloud System Models, or in short Cloud-Resolving Models (CRM), that explicitly represent the fundamental dynamical and microphysical processes (such as the indirect effect of aerosols on cloud particle growth) that determine precipitation rates and radiation fluxes.

Elements of this task are:

- Formulating effective CRM codes and incorporating essential features into climate models.
- Acquiring suitably detailed and comprehensive observations of cloud structure and optical properties, radiation fluxes, precipitation, atmospheric circulation parameters, and aerosols for testing CRM and global climate model representations. With the deployment of the "A-train" satellite constellation and future GPM missions, NASA is uniquely poised to acquire the full range of data required to address this problem.
- Developing and implementing the analysis and/or data assimilation schemes needed to reconcile model results with observations. This process with also enable the NEWS team to better guide future satellite observing capabilities.
- The implementation plan calls for an intensive research effort to develop new model computations of radiant energy, heat and water fluxes that resolve, at least partially, the characteristic scales of cloud process dynamics. (See sections 4.2.3 Modeling and 4.2.1 Observations).

Indirect Radiative Effect of Aerosols

As discussed in the Climate Change 2001 report (IPCC, 2001), anthropogenic aerosols have a direct impact on climate by increasing both the scattering and absorption of solar radiation. In addition, aerosols act as cloud condensation nuclei and affect cloud microphysics, thus inducing indirect effects by modifying cloud properties and their effects on the planetary radiation budget and precipitation. The level of understanding of these phenomena is very low, while the potential magnitude of indirect forcing by aerosols is quite significant (IPCC, 2001). This indirect aerosol forcing links both the energy and water cycles, and is an appropriate element of the energy and water cycle crosscutting program. Direct aerosol forcing is intensively studied and fully covered by the Atmospheric Chemistry and Composition Focus area and the Radiation Sciences Program (RSP). (See section 5.1.4) Although the direct effect of aerosol plays a key role in atmospheric radiation budget and climate, the energy and water cycle program does not cover all direct forcing issues and mainly focuses on the source, sink and trajectory of aerosols, the relationship of direct and indirect aerosol forcings, and unified modeling systems for aerosols and clouds.

There are several keys steps to isolate the indirect effect of aerosols that must be addressed in this program:

Aerosol effects on clouds must be separated from the effects of atmospheric dynamics. This requires sorting of a very large collection of observations and model simulations according to the synoptic situation.

- Aerosol chemical composition is generally unknown, but at least an approximate knowledge of the aerosol source region constrains this uncertainty (e.g. industrial origin, desert dust, forest biomass burning, grassland/agricultural burning, etc.). To make effective use of this information, improvements are needed in aerosol and atmospheric data assimilation, chemical transport models, and aerosol physics and chemistry simulations.
- Observations must establish that the aerosols and the cloud layer under consideration are co-located (same vertical layer, at the same time and same geographic location). This will typically require combined lidar, radar and radiometer profile data for cloud and aerosol vertical layering, as well as effective assimilation of aerosol data and source region information).

- Investigating a large number of cases is required to cover the range of cloud types and statistically reduce noise from weather phenomena that dynamically affect cloud properties. Extensive global cloud, aerosol, and weather information will be required for this purpose.
- CRM and Large Eddy Simulations (LES) dealing explicitly with cloud dynamics and microphysical properties in various (bin-resolved) size and composition categories will also be needed to complete the diagnostics and lead the way to global climate impact assessments. The coupling of CRM with atmospheric chemistry, aerosol and aerosol transport models expected under the energy and water cycle program and the capability acquired in the CRM development are critical to understand the indirect effect of aerosols.
- The first opportunity to effectively address the aforementioned issues will come with global data sets provided by the A-Train satellite constellation (CALIPSO and CloudSAT launch in Spring 2005) analyzed in combination with observations from heavily instrumented surface sites like those maintained by the DOE ARM project. In the near term, the implementation plan calls for exploiting new global observations and high resolution models. The NASA Radiation Sciences program and the DOE ARM program will be expected to support relevant field measurements addressing outstanding aerosol chemistry issues, and the absorption by black carbon.

Ocean Fluxes and Atmospheric Transport

The top of atmosphere (TOA) and the interface with continents and oceans are the two main boundaries between the atmosphere and its environments. Constraints on fluxes of energy and water through these two interfaces are important parts of the general circulation and atmospheric transport of heat and water. (note: very little water flux at the TOA is expected.) Large-scale changes in these fluxes may lead to changes in atmospheric forcings critical to the general circulation. The response of the hydrological cycle to rising concentrations of greenhouse gases is an important source of uncertainty for predicting future changes to Earth's climate and composition. The small amounts of water vapor in the upper troposphere (UT) exert high leverage in Earth's radiative balance. Of particular concern is moisture in subtropical regions. Measurements of H_2O in the upper troposphere (UT) will provide important new insights into how moisture is supplied to the subtropical middle and upper troposphere.

At the ocean-atmosphere interface, on-going data analysis projects already produce world-wide estimates of radiant energy and of latent heat (water vapor) fluxes, inferred (mainly) from satellite-based remote sensing of ocean surface temperature and winds, atmospheric temperature and humidity profiles, aerosol distribution, and cloud optical properties. Still both estimates are based on incomplete observational information (e.g. no air temperature or moisture data near the surface) and therefore rely on empirical approximations that are, by their very nature, difficult to validate under different climatic regimes. Thus, considerable room exists for further improvements in air-sea flux estimates, notably by exploiting new and more informative global retrievals of vertical temperature and moisture profiles reaching into the lower troposphere (AIRS, etc.), and of cloud/aerosol particle distribution and planetary boundary layer height (CloudSAT, CALIPSO, ICESat, TRMM and GPM). It is important to recognize the important role of the upper ocean mixed layer in controlling surface fluxes.

Another approach uses global assimilation of a wide variety of meteorological data into general circulation models. While such 4DDA analyses do reproduce transient weather patterns with considerable realism, flux estimates derived from model-based analyses or re-analyses are not reliable (mainly because of the flux increments that result from the initial adjustment of the model atmosphere to the assimilation of new data and the lack of appropriate physical constraints). Advances in model representations of atmospheric turbulence, boundary layer dynamics, and general model physics would help minimize these artifacts.

Furthermore, it is unlikely that any satellite-based remote sensing system would deliver wind profiling measurements with the sampling density and precision required for determining directly both the rotational and divergent components of the atmospheric wind field in the foreseeable future (10-15 years), although key information on surface winds over oceans is available Absent direct measurements of wind, estimates of sensible and latent heat (water vapor) transport by the atmospheric circulation will continue to be compromised by systematic model errors, especially faulty representations of the radiant energy and latent heat sources that drive atmospheric flow divergence. Thus, closing the energy and water budgets on the atmospheric side will remain an outstanding problem for some time.

On the other hand, the (relatively) slowly changing ocean storage and transport of heat and fresh water provides another view of the global and regional energy and water budgets on the oceanic side. Baroclinic weather systems, precipitation patterns, and indeed the global water cycle are governed by latitudinal temperature gradients that result from net solar radiation, ocean poleward heat transport and storage. Observations of the oceanic heat and fresh water storage and transport (especially, Aquarius and various *in situ* measurements) under the ESE Climate Variability and Change research focus area (see section 5.1.1) are directly applicable to determining energy and water budgets at the surface of the ocean, and constraining flux estimates based on atmospheric data. Conversely, changes in the deep ocean circulation are thought to be primarily sensitive to changes in river discharge into the North Atlantic reducing the density of surface water and the rate of North Atlantic deep water formation. This is recognized as a major scientific issue in the NEWS science plan and climate change research in general, including international activities supported by CLIVAR and CLiC.

Efforts requiring support by the overall NASA energy and water cycle program include:

- Analyzing sea surface fluxes obtained from multiple satellites and providing consistent estimates of energy and water transport between the boundary of atmosphere and ocean.
- Developing new techniques to measure the atmospheric moisture transport and reducing the errors of energy and water budgets in global reanalyses.
- Linking estimations of the TOA radiation balance and zonal heat transport to the ocean heat storage and atmosphere and ocean heat transport.

Although closing the energy and water budgets on the atmospheric side will remain an outstanding problem for some time, globally indirect observations of heat and moisture budgets should be exploited.

Land Hydrologic Processes

Evapotranspiration is the principal active link between land and atmosphere in the energy and water cycle. Additionally, runoff - and its progression into river/reservoir systems - is crucial to water-resource management and hydrologic predictions. Advances in remote sensing during the past decade, the development of land models to simulate hydrologic, geophysical and biogeochemical processes, and data assimilation techniques have led to considerable progress in computing water fluxes over the vast range of land classes that span the globe. However, substantial uncertainty in these land surface models and their application to practical hydrologic forecasting.

One measure of the uncertainties in these complex computational schemes is the large inter-model differences in global hydrological fluxes estimates. Moreover, current observational knowledge is insufficient to constrain these model differences. At the current stage, it is equally important to minimize uncertainties in all three aspects of the problem: model representations of the diversity of soil properties and hydrologic processes, quality and/or fidelity of observations, and assimilation techniques for merging disparate data sets. NEWS implementation calls for:

- Formulating single-column and 3-dimensional process models that explicitly or statistically resolve all critical spatial scales and simulate all governing processes which couple the land hydrology to the atmospheric boundary layer and general circulation.
- Developing more capable coupled land and atmosphere data assimilation systems based on the advanced models, to exploit the full range of observations from existing and planned satellite missions (Figure 2.1) and other relevant datasets.
- Assembling sufficient site-specific field data sets and global observations to test the range of parameters characterized by advanced models.
- Seeking improvements in pedologic, geologic and vegetation data sets that are required fixed inputs for land modeling.

Knowledge of the storage of water, over land regions, is vital to predicting the longer-term variations and trends in the global water, energy, and carbon cycles. Key reservoirs include: soil moisture, soil freeze-thaw conditions, snow and ice cover, groundwater, and inland water bodies such as lakes and rivers. Despite the importance of these storage terms, the fact remains that no long-term, global-scale measurements are available. Remote sensing from space now has the potential to effectively quantify these water storage terms.

In this context, the implementation plan calls for exploring and developing the means to extract water storage information from available or potential new remote sensing data, specifically:

- Validate retrieval algorithms and data products against *in situ* field and airborne observations
- Explore the feasibility of innovative satellite observing techniques (e.g., GRACE) for global detection of changes in hydrologic quantities such as water storage.
- Assimilate water-storage retrievals into appropriate hydrologic prediction systems to assess their consistency and impact on prediction skill.

In addition to this effort to upgrade current data retrieval and analysis, it is considered equally important to revisit and improve historical datasets. The implementation plan calls for reprocessing legacy data sets with the latest retrieval algorithms to merge with newly acquired information and produce consistent extended time series, for the purpose of assessing the significance (predictability) of historical extreme events and trends.

3.2 Key Tools for Energy and water Cycle Research

Advanced Global Observations

Global observations of energy and water cycle variables are needed for three quite different purposes. First, long term records of significant climate and hydrologic indicators are needed to characterize the variability and explore the predictability of the global energy and water cycle, based on observed characteristic time scales (frequency spectrum) and apparent responses to quasi-instantaneous disturbances. Second, comprehensive observations of (ideally) all aspects of the complex processes involved in the global energy and water cycle are required to explore the interactions between these processes and conduct penetrating tests of their numerical representations. Finally, complete observation-based determinations of relevant state parameters are needed (ideally) to initialize model predictions. It is expected that observation requirements for process studies and energy and water cycle predictions will be further refined in the course of NEWS implementation.

While many important hydrologic processes can be characterized from *in situ* measurements alone, satellite observations are essential to embrace the global energy and water cycle, which involves global atmospheric dynamics and global fluxes over land and oceans. Satellite remote sensing also provides extensive information about Earth system variables in regions where *in situ* measurements are sparse or their timely availability is precluded by political considerations. In situ measurements are nevertheless a critical component of any combined observational data set, and are necessary for validation and assessment of the information content of space-based observations.

The implementation plan calls for a specific effort to maintain critical global climatological records of essential atmospheric and hydrologic indicators. The calibration and independent verification of these records are critical for long-term energy and water cycle monitoring and modeling studies. The implementation plan also calls for systematic investments in scientific and conceptual studies and technological developments to further improve both measurement techniques and information retrieval methods relevant to the global energy and water cycle.

Climate and Hydrological Change Indicators

The principal indicators of variability or trends in the global energy and water cycle and land hydrology are radiant energy fluxes at the top-of-the-atmosphere (TOA) and surface, surface temperature, atmospheric temperature, humidity, and cloudiness, global precipitation (ideally both liquid and solid), terrestrial water storage distribution, and river discharge. Surface temperature, atmospheric state variables, and TOA radiation will likely continue to be adequately monitored by existing and planned meteorological space- and surface-based observing systems, particularly EOS Terra and Aqua, NPP, the NPOESS program, and European METOP satellite series.

Estimation of tropical and global precipitation is the focus of the TRMM and GPM missions respectively. To fill the period before the launch of TRMM, and the potential gap between TRMM and GPM, the international GEWEX Global Precipitation Climatology Project (GPCP) is producing a coherent (though possibly biased) long-term record of global rainfall. The GPCP product is based on merged information from different operational observing systems (infrared radiometry from geostationary meteorological satellites, microwave radiometry from DMSP and NPOESS, and land-based rain gauge networks). However, there is also a need for higher time-resolution measurements of precipitation: GPM is a major first step, but the more extreme precipitation events have time scales less than 3 hours. The technology for precipitation measurement from geostationary orbit needs to be developed.

Terrestrial water storages, including reservoirs in the soil, snow, and ice, vary over a range of time and space scales. Gravity field observations from GRACE can provide information on the variability of the total columnar water mass. Microwave radiometer and radar measurements from AMSR-E and SeaWinds provide the potential for monitoring the variability of snow water equivalent and near-surface soil moisture. Future soil moisture missions, and a possible cold lands research mission, will improve the accuracy, resolution, and coverage of the soil moisture and snow measurements. Additional analysis and development work is needed to integrate the data from these missions with hydrologic models and obtain useful estimates of water storages and their variability at different time and space scales.

Accurate river stage or discharge data are most readily obtainable, in principle, from stream gauging stations around the world. Unfortunately, not all important river basins are adequately gauged, nor are stream flow data generally available, certainly not in near real-time. On account of existing difficulties in the international exchange of hydrologic data, global satellite-based observation of river discharge and stage of inland water bodies must be considered. Several types of experimental altimeter and possible Doppler radar or lidar systems are being envisaged for this purpose (Surface Water Working Group).

Hydrologic and Atmospheric Process Observations

A great deal more observation-based information is needed to study and successfully model the physical, chemical, and biogeochemical processes that contribute to the global cycling of energy and water. Additional data are needed to understand hydrologic and atmospheric processes, construct and test stand-alone and coupled numerical representations of the processes, and measure progress achieved in predictive performance of advanced climate models. Additional data requirements include global observation of 3-D cloud system structure, ice particle and water droplet distributions within clouds, cloud optical properties, rain drop distribution and inferred rainfall, boundary layer height and vertical structure, soil hydraulic properties and surface wetness, evapotranspiration, and high-resolution information on vegetation type, water content, and aerodynamic roughness.

Process-oriented field studies and high-precision systematic measurements at experimental stations or sites are crucial data sources for basic energy and water cycle studies, but do not usually cover the whole range of hydrologic and meteorological regimes. Global sampling provided by NASA research satellite missions and other advanced remote sensing systems are crucial to complement systematic measurements and penetrate the basic physical, chemical, and biogeochemical processes that underpin the energy and water cycle. Important new observing tools that support NEWS process studies include EOS Terra and Aqua, forthcoming CloudSAT and CALIPSO and GPM satellites, prospective soil moisture and Aquarius missions, the European ENVISAT and SMOS missions, and potential new sensors.

Initial Value Data

With the exception of deep aquifers, energy and water cycle processes in the atmosphere and over land span a range of characteristic time scales from hours to several months or seasons. Thus, progress in *developing* the capability to predict changes in the energy and water cycle can be validated by comparing deterministic weather forecasts and/or seasonal to inter-annual climate predictions against a large enough number of independent observed variations. For this (regional) purpose, it is convenient to uncouple the regional energy and water cycle dynamics from the full climate system, and initialize regional atmospheric and land hydrologic variables only. Thus, the principal additional data requirements for NEWS (beyond numerical weather prediction requirements) are initial values of land water storage, i.e. soil moisture, snow, inland water bodies, and/or the depth to ground water. Energy storage in the ocean is also a necessary initial condition for long-time-scale predictions.

Several approaches for obtaining these data (and using them to initialize predictions) are being or will shortly be tested, including methods to infer soil moisture, vegetation water content, atmosphere-land interaction, and snow water equivalent from combined satellite microwave, visible and infrared data (using both passive and active sensors on DMSP, Aqua, and SMOS), satellite altimetry of river cross-sections and inland water bodies (potential "surface water" survey mission), and the recovery of transient variations in the Earth gravity field associated with changes in total water mass (GRACE). However, none of above methods has delivered fully satisfactory information so far, either singly or in combination.

An outstanding problem is continent-scale observation of critical cold weather hydrologic quantities: solid precipitation, water equivalent of snow on the ground, frozen or thawed state of the ground. Seasonal snow cover and glaciers store large amounts of fresh water. Seasonal and permanent soil freezing severely reduces the infiltration, storage and migration of ground water. The influence of seasonal and permanent freezing further extends to vegetation phenology and carbon fluxes, cold region engineering, trafficability, and a variety of cold land hazards.

Advanced Radiative Transfer Methods

Satellite remote sensing requires inverting the radiative transfer equation to retrieve geophysical quantities of interest. In view of the sensitivity of retrieval products to even small changes in outgoing radiation, the inversion (retrieval) process must be based on the best possible radiative transfer model(s) that cover all wavelengths from UV to microwave, discriminate polarizations in incoherent and coherent radiation, and accommodate both passive and active sensing techniques. To support the development of advanced satellite retrievals, radiation transfer models must have physically consistent representations of atmospheric composition, cloud ice and water particles, hydrometeors and precipitation, surface roughness, and vegetation or soil properties across the whole electromagnetic spectrum. Models should specify each component in terms of physical variables (even if values have to be assumed) instead of empirical relationships, and aggregate detailed scattering and emission parameters on satellite footprint scales. Further advances in fundamental quantum physics and spectroscopy may be required to accurately model continuum absorption and emission of gases.

Radiation transfer codes that fully satisfy these requirements do not currently exist. The development of more accurate radiation transfer models is the fundamental underpinning of any major new advance in satellite remote sensing. The implementation plan calls for the development of a new generation of radiation transfer codes for remote sensing applications. The radiative transfer processes for wavelengths from UV to microwave for irregularly shaped objects and uncommon size distributions, and in complex inhomogeneous media, such as ice and snow particles and snow packs, grass and tree leaves and vegetation canopies, and soils, are major difficulties of radiation calculations, and must be investigated deeply.

Most current retrieval techniques exploit only a few selected wavelengths from a single satellite instrument, and therefore do not provide either the best analysis of the available satellite data nor total physical consistency across data products. New, faster retrieval techniques (e.g. adjoint model equations or statistical-inverse models) must be developed, that are general enough to allow the simultaneous retrieval of a range of geophysical quantities from multiple wavelength, multiple sensor and multiple platform measurements. Such methods must be based on rigorous forward models of the measured radiation. The implementation plan calls for the development of advanced multi-variate retrieval methods that can exploit the totality of the spectral information acquired by Aqua and the "A-train" satellite constellation, and eventually analyze data from the whole energy and water cycle observing system. The development of more powerful radiative transfer codes and multi-variate retrieval methods is a prerequisite for acquiring crucial information for the success of NEWS.

Earth System Modeling

Modeling and analysis are a key means of making predictions and of integrating the NASA Earth Science focus area results into a comprehensive understanding of the Earth system. Modeling and analysis requirements are diverse, encompass a multiplicity of spatial and temporal scales, and involve a hierarchy of models from comprehensive, global, Earth system models to local, more process-oriented models. The major elements of the modeling and analysis effort within NASA's Earth science research program are: Create data assimilation capabilities for available diverse data types; Develop computational modeling capabilities for research focus areas; and Participate in national and international scientific assessments. The NASA Modeling and Analysis Program (MAP) supports development of the Finite Volume through the Goddard Modeling and Assimilation Office (GMAO) and the Gridpoint Statistical Interpolation (GSI) data assimilation developed jointly with the National Centers for Environmental Prediction (NCEP) within the Joint Center for Satellite Data Assimilation. Other modeling systems supported by NASA earth science programs include but are not limited to the Land Information System (LIS), Community Climate Model (CCM), WRF, Land Data Assimilation System (LDAS), ModelE and RAMS. It is vital that NEWS interacts with other National and International modeling groups to optimize development of next generation modeling and analysis capabilities. The Earth System Modeling Framework is designed to facilitate the integration and coupling of model components across disciplines and programmatic boundaries.

Computational models of the climate system play a central role in any effort to understand, simulate, and predict variability and changes in the Earth geophysical, chemical, and even ecological environment. Considerable talent and resources are already being invested in the further improvement, validation, and scientific exploitation of climate models. Regarding the global energy and water cycle, however, all model development efforts face two overarching scientific challenges: 1) The gap between the scales of atmospheric motion that are explicitly resolved and the scales where cloud, boundary layer, and hydrological processes actually occur; and 2) The gap between model output quantities and the geophysical variables that can actually be observed and measured in nature. This gap hampers defining climate prediction metrics that account for both natural variability and forced responses. NEWS and the scientific community must continue to develop methodologies and modeling systems that can adequately fill gaps between spatial/temporal scales and the use of observations to assess model uncertainty.

Global Energy and Water Cycle Model Development

An important goal of the NASA energy and water cycle study is to develop coupled interactive earth system models that link the atmosphere, oceans, land masses, and biosphere into a comprehensive whole. Model-assimilated data sets provide an improved description of much of the global system and its interacting components, and can be invaluable for addressing the major NEWS challenge of tracking global and regional variability in the energy and water cycle. The production and evaluation of analysis of the Earth system are necessary steps in the development of accurate and useful coupled land, ocean and atmosphere data assimilation and prediction systems for the global energy and water cycle. The scales resolved by this analysis must include diurnal to centennial time scales, and individual catchment basins to global spatial scales. The full spectrum of energy and water processes in the system must cover cold and warm season, high and middle latitude, subtropical, and tropical regions, and atmosphere, land and ocean from the subsurface to the top of the stratosphere. To enable application to water resources, streamflow, soil moisture, evaporation and precipitation must be realistically represented.

The ultimate demonstration of NEWS scientific advances is to be found in the development of a new generation of climate models that account for all significant physical parameters in the climate system and testing decadal or longer model predictions against past and current climatological records. The implementation plan call for the cooperation of interested modeling teams to develop and test potentially revolutionary model formulations that resolve - at least statistically - the characteristic space- and time-scales of atmospheric energy and water processes and explicitly represent relevant basic parameters. Advances in computing technology now make it possible to implement such process-scale resolving representations that have the potential for more closely reproducing the highly non-linear behavior of atmospheric processes and delivering much improved approximations of energy and water fluxes.

Cloud, Precipitation and Radiation Processes

The representation of cloud dynamics and microphysics is a major source of uncertainty in global modeling, which induces serious errors in model computations of radiation transfer and precipitation. Errors in radiation fluxes and flux divergence (radiative heating/cooling) directly impact the accuracy of predicted changes in temperature gradients and baroclinic synoptic-scale systems, which in turn control rainfall. Furthermore, cloud processes and properties may respond, through micro-scale physical processes, to changes in "external parameters" such as natural and artificial aerosol distribution or aircraft condensation trails. Further refinements of microphysical models are required to address the formation and growth of cloud particles in the saturated-vapor environment produced by atmospheric motions and the role of aerosols as condensation nuclei.

The NEWS modeling strategy supports use and development of comprehensive process-resolving Cloud-Resolving Models (CRM) that explicitly represent the principal features of cloud system dynamics and basic microphysical processes (such as the indirect effect of aerosols on cloud particle growth). CRM outputs are comparable to single-column parametric formulations of cloud processes in climate models but, unlike the latter, effectively account for the diversity of cloud systems and cloud properties within resolution elements of general circulation model. The NEWS implementation plan calls for exploring alternative methods for estimating radiation fluxes, latent and sensible heat fluxes, and rainfall based on CRM dynamics and microphysics, sampling if necessary the spatial/temporal diversity of cloud systems within GCM grid cells. Comparison of CRM results with detailed field data such as that collected through existing in-situ and space-based sensors in a variety of selected meteorological situations will be required. Additional unique observation data sets from CloudSAT, CALIPSO, and GPM will be available to test CRM performance in the near future.

The NEWS modeling strategy must be able to systematically apply the results of process-related studies across the whole range of models ranging from CRM’s to CGM’s. Such studies especially apply to the use of small-scale process models to test general circulation model representations directly. The latter usually involve approximations to account for the fact that the smaller-scale atmospheric motions are not explicitly represented (they, too, are parameterized), whereas the former determine these motions explicitly. This type of investigation is not a new idea but the problems are that the small-scale models often represent other physics (including cloud microphysics and radiation) with less sophistication than the GCM, even though their dynamics is better determined, and that modelers working with one type of model are not usually able or cannot work with the other type of model. This type of investigation requires multiple model types to be used together and must also define observational tests for comparing the process representation at all scales. The limited area Weather Research and Forecast (WRF) model is a viable tool applicable to the scale issue. WRF is highly flexible and can be implemented at coarse resolution to study complete synoptic-scale systems and high resolution in cloud resolving mode. Such mesoscale modeling systems can be compared with CRM and

GCM systems with full or sampled representations of cloud-scale dynamics and physics. Finally, advanced cloud process representations will be incorporated in global climate models to replace simple single-column parameterization schemes and the outcome will be tested against global satellite observations and available field measurements.

Land Hydrologic Processes and Evaporation

Land hydrologic processes are most crucial for determining hydrologic variations and extremes that directly affect human safety and property. Equally important, the varying contrast between continental and marine climates is a controlling factor in the earth climate system, as shown by the seasonal monsoon regimes. In addition to large-scale atmospheric circulation and wave patterns, spatial and temporal variability in rainfall and surface radiation, combined with land surface heterogeneity, cause complex variations in all processes related to surface hydrology. This variability constitutes a major challenge for climate system models. The characterization and proper model representation of spatial and temporal variations in land hydrologic processes are critical to understanding land surface-atmosphere interactions and resulting climate extremes, especially floods and droughts.

There are a number of issues that the NEWS modeling strategy must address. Large errors in simulated ground and near-surface air temperature can be traced to poor handling of the surface radiation budget, latent heat exchanges associated with evaporation, and soil freezing or thawing. Likewise, snow and frozen ground in late spring appears to have a lasting effect on weather patterns. In this manner, land hydrological processes may induce positive climate feedback that could enhance extremes of drought, or heavy precipitation and flood. Furthermore, snowmelt is a significant contribution to river flow and can be a major water resource in some mountainous regions. Reliably modeling the partitioning of rainwater and snowmelt among evaporation, ground storage, and run-off is a prerequisite for quantitative application of climate predictions to water resource management.

The principal obstacles hampering progress in land surface hydrology are incomplete observational knowledge of relevant land surface properties at the required spatial resolution over the world's continents, poorly resolved model representations of hydrological processes, and incomplete coupling of land-surface modules with the free atmospheric circulation. It is possible that CRM’s informed with appropriate data will provide an effective framework for developing physics-based representations of land hydrologic and boundary layer processes, and for testing statistical sampling schemes applicable to the estimation of land surface fluxes in global climate models. The implementation plan calls for addressing these deficiencies through better utilization of currently available land surface and water storage data, experimental process models, and comprehensive verification against intensive field measurements, aircraft observations, and large-scale diagnostics based on satellite observations.

Ocean Climate and Marine Boundary Layer

Latent and sensible heat fluxes from oceans are obviously crucial inputs to the earth climate system. On the relatively short characteristic time-scales of energy and water cycle phenomena, ocean dynamics may be taken as specified. Nonetheless, fast variations in heat and fresh water content occur within the upper ocean mixed layer, in response to changes in air-sea fluxes, rainfall, and solar radiation. The implementation plan calls for improvements in GCM representation of marine boundary layer turbulence and upper-ocean mixing, for more reliable atmospheric model computations of heat and water fluxes, and more accurate retrievals of flux quantities from satellite observations.

The new ability to produce seasonal through decadal estimates of global ocean surface radiation, heat, and fresh water fluxes provides the means to close the energy cycle on decadal time scales for the first time. The completion of the deep ocean ARGO float array, together with global satellite-based measurements of ocean surface temperature, salinity and height enables determining the time-dependent upper-boundary conditions and initial oceanic state variables to predict future changes in the world ocean circulation. Global ocean data assimilation products would in effect constrain the integrated effect of diverse ocean mixing processes and help quantify poorly observed phenomena, such as sporadic deep ocean mixing events akin to atmospheric convection.

The implementation plan calls for cooperation with ocean data assimilation experts and finding innovative ways to use global satellite and *in situ* data sets to understand the coupled ocean-atmosphere energy cycle. Improvements in knowledge of fast atmospheric processes, such as cloud effects on energy fluxes and precipitation, are also expected to yield improved predictions of ocean surface boundary conditions. Also required is the cooperation of ocean modelers to exploit new information on ocean vertical mixing processes and improve model predictions of future ocean heat transport and state variables, including sea-surface temperature that strongly influence atmospheric circulation at all time scales.

Global Energy and Water Cycle Model Validation

The value of model-based climate predictions hinges on the ability to demonstrate the verisimilitude of model simulations of intrinsic climate variability and climate response to observed disturbances (forcing). A major difficulty stems from the enormous number of degrees of freedom encompassed by the climate system, which makes any holistic verification very difficult. In the past, climate models have been tuned to replicate observed mean states of temperature, radiation, wind, etc. This is widely understood as insufficient; coupled climate system models will have to be verified on a number of levels. There are too many ways to arrive at a particular climate state through adjustments of individual process parameters and not enough known independent events to unravel the complexity of the system and identify a unique cause for each discrepancy. Higher order moments of variability for energy and water fluxes, frequency distributions of state variables, and other objective measures of variability will be needed to assure that the energy and water physics packages produce a realistic climate. Many of the observables discussed in sections 3.2.1 and 3.2.3. will have to be analyzed in similar fashion and used to quantify the realism of the improved prediction system. Listed below are some candidate methodologies.

Measuring progress in climate models according to objective metrics is the other major problem. Comparisons between model predictions and global (large-scale) climatological data derived from measurements provide necessary but insufficient constraints. First, climate signals may be below the level of natural climate variability (noise). Second, there may be many possible ways to adjust model algorithms so as to match global mean quantities, such as global rainfall, because there are too many feedbacks and forcings to tie down causes and effects unambiguously. A possible complementary approach is validating climate models in numerical weather prediction (NWP) mode, i.e. compare deterministic predictions to observed instantaneous variations. NWP allows a clearer test of individual processes such as clouds and precipitation, moreover it is well known that physics bias in climate models tend to occur early on in the numerical integration, and that they can be better detected during the early stage of the integration, before the large scale effects dominate. However, the NWP approach also has serious (but different) shortcomings. First, weather prediction noise is so large, that subtle climate feedback processes are unlikely to be tested at sufficient accuracy. Second, ocean fluxes and atmospheric feedbacks are uncoupled in NWP, so that critical variables like vertical velocities are poorly determined. A possible approach to overcome NWP shortcomings may be analyzing large ensembles of weather cases grouped by dynamical state such as cloud type or atmospheric state variables, or extending both prediction and verification to seasonal or even interannual time scales. The implementation plan calls for climate model tests over a wider range of time and space scales, and more penetrating analyses beyond the examination of simple grid-box averages (see section 4.2.2).

The implementation plan calls for modeling research proposals that define suitable performance metrics based on the comparison of model products with relevant observations. Potential validation strategies are:

- Off-line testing of individual process modules or combinations of modules (one-way coupling with the atmospheric circulation) by comparing process model outputs with detailed field measurements over selected experimental sites. This method is likely appropriate for testing individual process formulations when necessary boundary conditions can be defined from observations and assimilated in the process model.
- Testing global model products in a deterministic NWP mode over a large number of independent weather events, using observed initial values and transient boundary conditions as appropriate. This method is likely appropriate for evaluating, over short to intermediate time periods (days to a week), model computations of fast processes closely linked to, or driven by weather dynamics, e.g. the life cycle of cloud systems, rainfall, flash floods, etc. The implementation plan calls for the participation of climate modeling teams who can invest in the development of appropriate data assimilation procedures and process diagnostics, and/or the participation of weather prediction teams who can upgrade the formulation of physical process to match the performance of climate models.
- Testing ensembles of climate model predictions over a number of test cases of seasonal to interannual changes or anomalies in the atmospheric circulation and hydrologic regimes. This method is likely suitable for testing model simulations of phenomena with longer characteristic time scales, such as atmospheric circulation blocks, changes in water storage, extended flooding events, or long-standing anomalies in the upper-ocean heat and fresh water content. The implementation plan calls for investing in the development and exploitation of expanded data assimilation and "spin-up" techniques for initializing the relevant model parameters in addition to conventional atmospheric variables (e.g. soil moisture, snow mass).
- Testing ensembles of decadal or longer term climate and hydrologic prediction by comparing to past and current climatological records. More penetrating tests of integrated model formulations of climate dynamics and thermodynamics may be possible by comparing computed second-order quantities, such as fluxes or energy conversion rates, with statistics derived from the whole range of global measurements. The implementation plan calls for the development and maintenance of these diagnostic tools and long-term global climatological data sets.

Coupled Data Assimilation Systems

Data assimilation is an objective method to estimate the state of the earth system by integrating a numerical model with irregularly distributed observations to develop physically consistent estimates that more completely describe the Earth system state than the raw observations alone. This process is the fundamental paradigm for providing initial conditions for Earth system prediction, and for increasing our understanding and parameterization of Earth system behavior through various diagnostic research studies. Data assimilation has great potential to advance the understanding and prediction of the global energy and water cycles by combining large amounts of heterogeneous land, ocean, and atmosphere observational data into a coherent whole. Data assimilation is especially valuable in isolating systematic errors and biases in satellite observations, and for assessing the impact of future satellite observations within prediction systems.

Most current data assimilation efforts utilize separate, uncoupled (i.e. inconsistent) atmosphere, ocean and land modeling systems. The uncoupled approach fails to maximize information extracted from the growing suite of remote sensing measurements. Further, energy and water cycles are not adequately described by current model analysis systems, with analysis increments resulting in important non-physical contributions to the global energy and water budgets. Analysis errors are often the sum of large compensating errors in individual processes, including precipitation, and surface and atmospheric fluxes.

While truly coupled assimilations will be needed eventually to improve coupled predictions, the current separate land-ocean-atmosphere data assimilation methodology provide a better description of the global energy and water cycles due to inadequate understanding of feedbacks between the complex subsystems. For example, current uncoupled Land Data Assimilation Systems (LDAS) use observed precipitation and solar radiation as forcings (not true coupled assimilation), to avoid cloud and precipitation errors that are characteristic of coupled systems. It is precisely these fluxes or energy and mass exchanges that are at the heart of Earth system feedbacks and which, at present, are so uncertain in coupled models. To achieve the goal of fully coupled atmosphere-land data assimilation systems that should produce the best and most physically consistent estimates of the energy and water cycle NEWS will need advanced coupled process models with improved feedback processes, better observations, and comprehensive methods for coupled assimilation.

The elements of this effort are as follows:

- Identify and obtain all relevant observations of precipitation, snow, soil moisture, upper atmosphere humidity, evaporation, and other components of the energy and water cycle, implement an integrated, multicenter, nationally focused archive system for these observations, and model-assimilated and-tested data sets and provide for ready access to these data sets by the scientific community over the long term.
- Assess closure of the observed global and regional energy and water budgets over various timescales to provide benchmarks for model based analysis and prediction methodologies.
- Develop methods to assimilate measurable components of the energy and water cycles, including precipitation, cloudiness, radiation, evaporation, temperature, humidity, vegetation, soil moisture, groundwater, cryosphere, etc.
- Perform Observing System Simulation/Sensitivity Experiments (OSSEs) to specify the requirements for new observation systems.
- Develop more realistic energy and water process models, especially those associated with convection, clouds, land surface, and boundary layer processes.
- Compare energy and water processes from different model analyses to better understand uncertainties, with particular attention paid to spinup, observation evaluation, and the behavior and role of analysis increments.
- Develop coupled land-ocean-atmosphere data assimilation systems that achieve internally consistent, accurate and unbiased estimates of the energy and water cycle.

- Establish graduate education and research opportunities in four-dimensional geophysical data assimilation to provide essential expertise.
- Improve ability of assimilation models to accurately depict regional, zonal, and global trends, which are not handled well in current assimilation products. Run models in a frozen analysis system for climate data applications.

Advanced Analysis of Multiple Data Sources

New approaches to the analysis of satellite measurements, data assimilation products, and forecast model outputs are necessary to solidify our understanding of global energy and water cycle variability and trends. The deployment of the Earth Observing System and associated Pathfinder missions (A-train) accentuates the need for new methods to integrate data from multiple sensors and platforms and to extract information from these data on the spatial and temporal characteristics of energy and water cycle processes. Analyses of current data sets will identify gaps that need to be filled to complete a comprehensive global observing capability.

The implementation plan calls for more informative satellite data products generated by merging data from multiple sensors and platforms. Examples are different measurements of a single quantity (e. g, vertical profiles of a quantity in different altitude ranges and total-column amounts) and flux estimates derived from measurements of several parameters. Such products require co-registration of multiple sensor data, possibly from different satellite or sensors, and the application of single-column retrieval algorithms or fully 3-dimensional data assimilation systems for generating physically consistent fields of energy and water cycle quantities. The implementation plan calls for developing optimal techniques to merge disparate data sets, algorithms for assimilating physical data products into atmospheric and surface process models, and estimates of associated error characteristics.

In order to quantify and understand the variability of the energy and water cycles, satellite and model-assimilated data products need to be analyzed in ways that illuminate the spatial and temporal features of the individual component quantities and their interactions over all critical time and space scales. The key satellite data sets must be cross-calibrated between platforms and sensors that overlap in time, making use of *in situ* data as independent standards. Methods for partitioning errors between different noisy datasets will be necessary to correctly identify geophysical signals in the presence of observational error. The implementation plan calls for assembling and maintaining, with minimal spatial and temporal gaps, consistently calibrated, long-term, global data sets such as radiation balance at the top-of-the-atmosphere, atmospheric temperature and humidity, cloud climatology, surface-radiation budget, precipitation climatology, etc.

Comparison of these enhanced data sets with relevant climate model products, and systematic *in situ* measurements or field campaigns will provide the basis for assessing the performance of retrieval algorithms, the consistency of *in situ* point measurements, and the error characteristics of derived data products. The analysis of field measurements will also support radiative transfer and geophysical process model developments, sensor calibration, and retrieval algorithm developments.

Deficiencies in current observing systems will be identified from the outcome of the above analyses and inferred error characteristics of global datasets, highlighting the critical gaps in observational capabilities of energy and water cycle. These diagnostics will constitute a scientific basis for new technology and mission developments, leading to future flight missions.

NEWS will critically examine studies of the time behavior of global precipitation rates and patterns as revealed by the integration of satellite and surface rain gauge data, with particular attention to the tropical oceans and possible secular changes. Assessing variability require homogeneous global rainfall information that can only be assembled from a combination of surface-based and space-based measurements.

Global estimates of evaporation will be inferred from multiple satellite data sets. Over the ocean, the feasibility of estimating evaporation from satellite data only has been demonstrated and still needs to be improved with or without combining remotely sensed data with full 4-dimensional assimilation of meteorological data. Over land, a combination of remotely-sensed data, state-of-the-art models explicitly representing dynamical, physical and biogeochemical processes, and data assimilation will be necessary to improve estimates of continental evapotranspiration. The implementation plan calls for estimates of global P – E budgets based upon combined ocean and land evaporation data, global precipitation data, upper-ocean salinity and ground water storage information, for the purpose of identifying regional trends in fresh water fluxes.

Analyses of global observations of cloud, water vapor, and boundary-layer properties, will improve our understanding of precipitation and evaporation (that control the rate of the global water cycle). In general, it is expected that the analysis of changes in water, radiant energy and heat sources and sinks over space and time will lead to direct an estimation of the sensitivity of the Earth's climate system to feedback mechanisms.

Global trends of soil moisture and freeze/thaw state will lead to better understanding of climate change impacts on cycling of water, energy, and carbon at the land surface, and will improve weather and climate predictions. Analysis of snow and ice cover and depth over land will enhance modeling of river basin response, stream flow forecasting, and surface energy balance for climate modeling. New altimetry and gravimetric data will be used to estimate river discharges and deep groundwater storage.

Technical Studies and Key Technology Requirements

NASA's Earth Science Program conducts a technology program that develops advanced technical capabilities for future science and applications systems. Advanced technologies provide the foundation for a new generation of sensors, instruments, information systems, and high-end modeling frameworks. When infused into mission systems, new technologies yield improvements in our ability to observe, process, and disseminate data and information products to ESE customers. The Earth Science Technology Office (ESTO) is responsible for development of a comprehensive technology-investment portfolio that meets ESE's science focus area needs identified in the science road maps.

For the Water and Energy Cycle focus area, ESTO will address the technologies (instrument, information systems, and computational) needed for new measurement capabilities, such as river discharge rate, river stage height, global soil moisture, and snow water equivalent.

Instrument Technologies

Present space-borne instruments only measure the moisture of the uppermost layer of soil, and there are significant limitations on the type of ground cover that can be present for measurements to be made. An instrument that could sense the soil moisture at root zone depth (1 to 5 m below the surface) would offer a tremendous advance in our ability to make meaningful measurements of global soil moisture, leading to a vastly improved ability to understand and model hydrological processes. A VHF/UHF/L-band SAR could yield high payoff here, since it is the only existing instrument concept for measuring soil moisture at root zone depth. (That is different from the concept of inferring the existence of water under the Earth's surface using gravity missions such as GRACE). Soil moisture at the surface can be measured with the same type of instruments used for measuring sea surface salinity. These include: 1) 25m real-aperture conically scanning L-band radiometer, 2) a 25m 2-D L-band STAR system, and 3) a 25 x 50m torus with pushbroom scanning.

Snow is a very important aspect of the water and energy cycle. For measuring snow water equivalent and snow wetness, the development of three technologies is recommended (no ordering implied. The first is a C- and Ku-band polarimetric SAR. The second is a 6 m conically scanning K- and Ka-band passive radiometer. This would be similar to existing instruments, except for the factor of 3 larger antenna, which would require new technology. The third is a 6 m K- and Ka-band STAR. One of these technologies, or better yet, a passive/active combination, would then serve as the future observing capability for snow water equivalent and snow wetness.

The freeze/thaw transition of the land surface and the length of the growing season is an important aspect of the water and energy cycle. The development of 3 technologies is recommended. First, the Ku-band SAR described in the above paragraph can also be used for measuring the freeze/thaw transition. Second, the Ku- and C-band SAR described in the above paragraph can also measure freeze/thaw transition. The third is a 25 m L-band Synthetic Thinned Aperture Radiometer (STAR) described for soil moisture measurement.

Global precipitation is obviously a very important aspect of the water and energy cycle. To make continuous measurements of atmospheric temperature, water vapor, and rainfall, a scanning microwave sounder in geosynchronous orbit can be used. A 4m aperture scanning radiometer is recommended for GEO operating in the 50 and 183 GHz bands. A STAR operating at 50 and 183 GHz should be considered as an alternative to mechanically scanned antenna. Also, the dual-frequency (14/35-GHz) precipitation radar option will allow coverage of light and heavy rainfall and snowfall. The other recommended instrument is an X- and Ka-band STAR, in which recurring per unit costs have been reduced, in order to enable a constellation to be flown, in order to realize short revisit times. Temporal resolution is extremely important to the measurement of precipitation, since it is so variable in time.

It is not currently possible to measure river stage height and discharge rate from space. This important aspect of the water and energy cycle is part of the link between the hydrological cycle and ocean circulation. The recommended instrument is a Ka-band InSAR operating in a cross-track mode. This initial proof-of-concept instrument could lead to an important ability to monitor the world's rivers on a routine basis, to improve the understanding, and ultimately the modeling, of the links between water on the land and in the oceans. Surface elevations, including ground topography, vegetation height and vertical structure, and river and lake stage can be measured using a photon-counting imaging lidar with sensor wavelength of 532nm. Also, scanning laser altimeter at 1064nm can provide landscape-scale (10km swath), high resolution (10m pixles), and 3-dimensional mapping of the earth's surface (vegetation and surface topography).

Information Technologies

- *Onboard Storage Architecture:* Instruments having greater precision and resolution will require increased on-board storage capacity in which to store instrument data prior to its transmission to the ground. New storage technologies will be essential in the implementation of the sensor web. Volumetric/Optical memory devices are projected to have a memory density of 0.2 bits/mm3 with an access rate of 2 Gigabits/sec.
- *Microprocessor, Board and Buss Technology:* These component technologies are critical elements in implementing an effective on-board processing capability. They are all related to

speed, flexibility and adaptability of the data collection, processing and transmission capability of the sensor system. Radiation-tolerant and radiation-hardened processing devices will improve central processor reliability in the presence of radiation-induced errors. Buss speeds are one of the notable bottlenecks in processing. Optical buss technology will provide a revolutionary increase in the rate at which data can be moved between processors, memory and peripherals. Processors that can execute 1 billion instructions per second will enable essential on-board processing functions needed to support the data manipulation requirements of sensor webs.

- *Lossless & Lossy Data Compression:* Data compression when combined with feature identification, compression can significantly increase the quantity of useful scientific data collected in a time interval. Lossless data compression has mathematical limits on compression ratio. Lossless compression rates at 220 millions of samples per second and with a 5:1 Compression Ratio approach these limits of performance capability. Lossy data compression is highly dependent upon the data source and upon the perception of the user.

- *High Data Rate Communications:* Current EOS systems employ X-band radio frequency technology, operating in the 7.25 – 8.4 GHz frequency band. X-band systems have been the mainstay of NASA high data rate (75 -150 Mbps) communications, but have limited available bandwidth to serve the increasing demand for throughput over the next decade. Future systems will need the wider available bandwidths provided in the 17.3 – 31 GHz frequency band which can transmit at 300 – 600 Mbps rate. Because of the much smaller size constraint of Ka-band hardware, this technology may also be suitable for use in satellite-to-satellite communication applications, which could provide support for networked satellite constellations. Optical communications technologies represent a breakthrough in terms of available bandwidth. Increases in data rate (~Gbps) could be several orders of magnitude over radiofrequency (RF) technology. Satellite to satellite communications will almost certainly require this technology.

- *High-Performance Evolvable Archives:* With multi- and hyperspectral data streaming in daily, the storage and archiving of Earth science data has become a new challenge. Tera- and petabyte storage media have become a necessity not only in the Earth science regime, but the entire digital world. Current File Storage Management Systems (FSMS) are primarily company proprietary products such as UniTree, AMASS, and FileServ. The ANSI/AIIM MS66 standard of 1999, Metadata for Interchange of Files on Sequential Storage Media Between File Storage Management Systems (FSMS), provides for a standard tape format, including file-level metadata. Future archives will require development of a database management system (DBMS) that accommodates swath geolocation data and evolvable storage media and formats including storage, archival, and retrieval standards. Advanced intelligent archives are also needed for knowledge discovery, extraction, and extrapolation.

- *Intelligent Platform & Sensor Control:* Autonomy will be an essential part of platform control. Intelligent systems will control the sensor web and integrate the platform with sensor measurement requirements. The projected intelligent platform technologies described here will enable a greater number of satellites to be controlled within the sensor web. The first generation capability will enable autonomous control and formation flying within a limited constellation of satellites and develop concepts for larger sized sensor webs. The second generation of autonomous control architectures will incorporate new software paradigms and algorithms in order to control a greater number of satellites. Agent-based reference architecture for multiple autonomous spacecraft (~50) is an essential capability for autonomous control of large numbers of formation flying satellites.

3.3 NEWS State of the Global Water and Energy Cycles Assessment

To harvest the anticipated NEWS achievements in observational and modeling capabilities, a "discipline of prediction and verification" (NRC, 1999) must be developed, maintained, and continually expanded. This framework must include the integration of observations and models and verification of model predictions against observed phenomena. The predictions would ultimately support reliable solutions for societies' environmental challenges. To achieve this pathway, we must first quantify the current cycling of water and energy, assess the water and energy cycles' predictability and limits-of-prediction and diagnose the skill of current models to predict that cycling. To address this goal, however, requires climate-quality, globally complete observations of the key rates and storages (e.g. Fig. 1). However, while recent advances in observational and computing capacity have provided vast new information resources, these disparate information sources must be integrated to produce a consistent global water and energy cycle depiction. Therefore, NEWS proposes to provide periodical state of global water and energy cycle assessments, which will evaluate the research community's current ability to detect, analyze, understand, and explain global water and energy cycle change, variability, predictability, and prediction. Such an assessment is called for by the Water Cycle chapter (chapter 5) of the Strategic Plan for the U.S. Climate Change Science Program (CCSP), in which a vision to assess the status and trends of global water cycling is expressed as an explicit milestone.

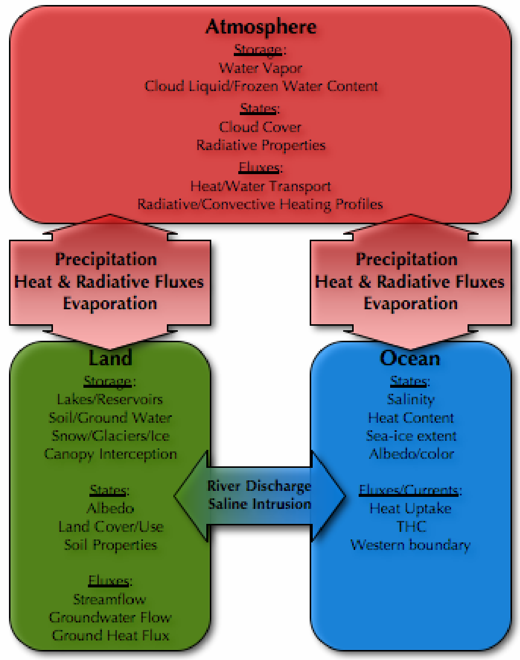

Figure 1.4. Major global water and energy cycle storages and fluxes to be included in NEWS assessments.

Data discovery and database building

This NEWS Assessment Newsletter (NAN) will require an integrated global water and energy cycle observation and model database including horizontal and vertical fluxes, column-integrated storages of water and heat, as well as other key/complementary state variables/fluxes/flows (Fig. 1), which will support diagnostic trend, transient variability and predictability studies. This database will have a global scope and climate-timescale perspective, and thus requires a complete understanding of global-scale teleconnections and feedback processes. Logistically speaking, this project will require data analysis tools that provide a broad range of capabilities, including data discovery, metadata search, distributed data access and analysis, and end-user display. For this purpose, we must rely on standard formats of data: such as HDF, netCDF, GRIB or binary and may be accessed over the Internet via standard data protocols (e.g. OPeNDAP). Thus whenever possible, we will link to internet data resources, rather than storing data "locally" to assure access to the most up-to-date datasets. Potential sources of water and energy cycle data include (e.g. Table 1): remote-sensing (Terra, Aqua, Grace, TRMM, AVHRR, GOES, ENVISAT, ERS, JERS, etc), global simulation and assimilation models (NCAR, NCEP, ECMWF, GFDL, GMAO, COLA, etc.), operational in-situ networks (radiosonde, surface networks, etc.), field experiments (LBA, GAPP, etc) and research networks (CLEANER, NEON, etc.). These data will have a wide variety of temporal and spatial resolution and availability and significantly different error characteristics, which will have to be documented and handled. Further, we will have overlapping datasets (i.e. precipitation from gages and remote-sensing) that will require value judgment or merging to establish the least biased estimate possible. The existence of overlapping datasets can increase confidence through cross-validation and can serve as “super-ensembles” (i.e. in the case for multiple modeled products) that can help to establish the uncertainty, predictability or variability of a water cycle process. We plan to rely on developing remote analyses capabilities (e.g. Greta, OPeNDAP), which can employ an “on-demand” approach, where specified parameters of an analysis operation combined with a specified space-time domain are used to dynamically create and serve a desired data set. Under such architectures, metadata searches can then supported via a web-browser interface and also via web terminal requests.

Table 1: Components of the water and cycles (with other tightly coupled carbon variables). "I" and "S" denote measurements made by in situ and space-based instruments, respectively (adapted from Table 12.1 of the 2003 CCSP strategic plan).

Variable	Ocean	Terrestrial	Atmosphere
Internal/ State	Upper ocean currents (I/S) sea surface temperature (I/S) sea level/surface topography (I/S) sea surface salinity (I/S) sea ice (I/S) wave characteristics (I/S) mid- and deep-ocean currents (I) subsurface thermal structure (I) subsurface salinity structure (I) ocean biomass/phytoplankton (I/S) subsurface carbon(I), nutrients(I) subsurface chemical tracers(I)	topography/elevation (I/S) land cover (I/S) leaf area index (I) soil moisture/wetness (I/S) soil structure/type (I/S) permafrost (I) vegetation/biomass vigor (I/S) water runoff (I/S) surface temperature (I/S) snow/ice cover (I/S) subsurface temperature (I/S) subsurface moisture (I/S) soil carbon, nitrogen, phosphorus, nutrients (I)	wind (I/S) upper air temperature (I/S) surface air temperature (I/S) sea level pressure (I) upper air water vapor (I/S) surface air humidity (I/S) precipitation (I/S) clouds (I/S) liquid water content (I/S)
Forcing/ Feedback	ocean surface wind & stress (I/S) incoming SW radiation (I/S) incoming LW radiation (I/S) surface air temperature (I/S) surface air humidity (I/S) precipitation (I/S) evaporation (I/S) fresh water flux (I/S) air-sea CO_2 flux (I) geothermal heat flux (I) organic & inorganic effluents (I/S) biomass and standing stock (I/S) biodiversity (I) human impacts-fishing (I)	incoming SW radiation (I/S) incoming LW radiation (I/S) PAR radiation surface winds (I) surface air temperature (I/S) surface humidity (I/S) albedo (I/S) evapotranspiration (I/S) precipitation (I/S) land use (I/S) deforestation (I/S) land degradation (I/S) sediment transport (I/S) air-land CO_2 flux (I)	sea surface temperature (II/S) surface soil moisture (I/S) surface soil temperature (I/S) surface topography (I/S) land surface vegetation (I/S) CO_2 & other greenhouse gases, ozone & chemistry, aerosols (I/S) evapotranspiration (I/S) snow/ice cover (I/S) SW and LW surface radiation budget (I/S) solar irradiance (S)

BLUE=Water Cycle Variable; RED=Energy Cycle Variable; GREEN=Carbon/Chemistry Variable; BLACK=Boundary condition

Data integration and analysis

A synthesis of global water and energy cycle data must be accurate, unbiased, and policy-relevant and available to a broad range of stakeholders. This task will require a systematic approach for data system integration that combines information from disparate sources to produce the most accurate single value of a target variable. The interpretation of the range of values for a single variable from different sources can lead to different conclusions. The development of essential tools such as prediction models, Geographic Information Systems (GIS), data assimilation systems, observational simulation experiments and data mining tools make the integration of different data streams feasible. Integration may also take the form of developing higher-level products, such as water balance information or observationally based model diagnostics. Here we define 3 aspects of data integration:

- ***Spatial and temporal rectification:*** The first order data integration technique will be to simply interpret relevant data to a common time and space domain for intercomparison and visualization. This will enable assessment of data set error and bias, as well as water cycle variability, uncertainty and predictability. Performing global water-balance analyses will further interrelate the data, highlighting gaps in our knowledge.

- ***Physical rectification or constraint:*** Data assimilation techniques merge a range of diverse data fields with a model prediction to provide the best estimate of the current state of the natural environment. This is an integration process that uses data from many sources, resolutions and its relative error. We will implement a number of standard data assimilation and data fusion tools to explore this kind of integration.

- ***Communication:*** Because of the highly specialized nature of earth science research, it is common for disparate research groups and stakeholders to be unaware of each other's activities. Therefore, enabling the sharing of data, ideas and techniques can an important integrating function. By collecting and distributing disparate water cycle data, creating NAN assessments, we will enable cross-group data sharing and integration.

The aforementioned "on-demand" data analyses architectures have very strong abilities to compare data sets from different environmental science specialties. Data in different formats, using different metadata conventions, on different grids, with different spatial-temporal registration, represented as different variables, both gridded and in-situ – all this data can be *easily* compared and cross-analyzed, without getting involved in the details of the data format nor the details of geo-registration of the data.

Model evaluation and assessment

An important aspect of NEWS will be to evaluate both observations and models in an integrated and coordinated fashion so that genuine improvements in our empirical quantification/detection, simulation and prediction of global water/energy cycle variations and trends are realized in global predictions. This task will be focused on diagnosing model output quantities that can actually be observed and measured in nature, or water/energy cycle budgets, trends and variability assessments. NEWS will produce innovative diagnostics that will identify deficiencies in individual process modules or combinations of modules, including results from off-line modeling systems (i.e. the Global Land Data Assimilation System), global data assimilation models (GFDL, NCEP, GMAO, etc.), ensembles of climate model predictions (e.g. IPCC AR4), and will test ensembles of decadal or longer term climate and hydrologic prediction. NEWS will develop the diagnostics and to use them to evaluate the output of modeling systems, but not perform the actual model integrations (these will be contributed or selected from the public domain). Through this analysis NEWS can determine how skillful current modeling systems are, identify model deficiencies and encourage prediction skill improvement.

Stakeholder interactions

An important objective of this project is to help describe the water management, socio-economic drivers, and anthropogenic interactions with the global water cycle. This will require identification and partnership with key water cycle stakeholder constituencies. Currently, NEWS has some formal but mostly informal affiliations with a wide range of national and international water cycle scientists, decision makers, managers, organizations and networks that will be matured and expanded in the latter phases of NEWS. Establishing a sound relationship with the stakeholders is an important first step in order to assess their needs. NEWS team members will accomplish this through structured interviews with relevant and potential stakeholders, as part of ongoing dialogues and future workshops. The design and content of the structured interview process is a top priority activity in order to establish the relevance of their feedback. Inputs will then be assessed to narrow the focus, followed by a planned strategy and approach to meet their needs. Dividing end user needs into separate generic categories, verifying that all information received is correct will aid in the mining of information that will be useful.

3.4 Key Application Benefits from NEWS

The primary goal of the NASA Global Water and Energy Cycle activity is to enable improved predictions of energy and water cycle consequences from Earth system variability and change. A critical component forthcoming from NEWS will be to assess and predict changes to the water cycle at various spatial (regional to global) and temporal (days to decadal) scales. Due to the crosscutting nature of water in the Earth System there is a broad range of applications that can benefit from improved understanding and prediction of the global energy and water cycle. Many of the goals of NEWS parallel the goals of the Earth Observation Summit Framework and the application objectives described in the 10-year implementation plan from the ad hoc Group on Earth Observations. Efforts in NEWS are towards developing the full potential for applications. Clearly, there is a goal of NEWS to closely tie together “science-applications-technology”. Moreover, the development of energy and water cycle global data sets and predictions will lead to an improved system benefiting both poor and rich nations. This will especially assist developing nations with inadequate quantitative observations thereby helping equalize the current widespread differences between countries.

The improved knowledge and predictions from these activities on regional weather and climate will provide information to meet the challenges confronting our society. Short-term heavy precipitation events from hurricanes and severe storms cause the highest monetary impact from natural disasters. NEWS will help lead an improved understanding and prediction of the integrated water cycle providing important information to reduce the effects from floods/heavy rainfall. Improving the short-term to seasonal prediction of floods will also permit water managers to determine optimal allocations for hydroelectric or agriculture usages. In addition, the amount and extent of snow in the water cycle, an important objective of NEWS, is also critical for flood prediction. The improved short-term prediction of water cycle events (<10 days) may cause dramatic improvements in early warning flood prevention, preparedness systems and flood assessment and relief management. Improved weather forecasts allow city managers to more accurately purchase energy contracts. If the accuracy of 30-hour weather forecasts improves 1°F, the annual cost of electricity can decrease by over $1 billion.

Being able to provide improved seasonal to interannual predictions to the global energy and water cycle will provide numerous ways for better resources management. A better prediction of the scarcity or abundance of precipitation will affect for example water managers determining the allotment of water for agriculture, hydropower, fisheries, and flood control potentially saving billions of dollars. With improved short term precipitation forecasts (e.g., 10-90 days), water resources managers may reduce (or increase) reservoir water amounts while potentially reducing the disastrous consequences from possible future heavy precipitation causing flooding, or on the other side, providing increase water flow for meeting societal (e.g., agriculture) and environmental (e.g., fisheries) needs.

Another crucial area is the ability to predict seasonal to interannual drought. The prediction of areas undergoing periods of drought may provide advanced warning to help mobilize and prepare to better deal with water shortages potentially saving large numbers of human life. Associated economic impacts to global crop production from drought are significant. More accurate predictability of those events may aid commodity price planning, agriculture water use management, and soil loss/stabilization management. Improved surface parameterization from incorporating land surface information such as soil moisture will significantly improve their predictive capability.

Many models suggest that due to anthropogenic changes there is an intensification of the water cycle leading to increased precipitation and evaporation yielding an increase in extreme events of floods and drought. A key question is to assess and predict by how much and where the water cycle is accelerating with possible links to anthropogenic versus natural induced variations. Natural variability of water and energy fluxes associated with shifts in the Pacific Decadal Oscillation, North Atlantic Oscillation, or other low frequency phenomena are likely to dominate decadal variability in the near term. Distinguishing these signals from anthropogenic effects (increases to greenhouse gases and aerosols, land use changes) is critical for providing scientific input to policy makers. It is changes to the water cycle, more so than changes to temperature that directly affect societal needs. However, current climate modeling research work is much further along with predicted changes to temperature than precipitation. The study of the integrated energy and water cycle system with an understanding and prediction of how components of the system interact will lead to better decision making for issues such as seasonal flooding, droughts and water supply. The NEWS will provide enhanced understanding of the effects from various human induced changes from burning of fossil fuels, land cover change, and emission of aerosols to changes to the water cycle. It is the quantification and prediction of these actions to the water and energy cycle that is of high importance.

In the previous section benefits associated from weather and climate were summarized. Clearly, due to integrative and pervasive nature of water study there are numerous benefits that may be discussed. A summary of some of the important application benefits from the implementation of NEWS in addition to Weather and Climate are summarized in Table 3.4.1.

Table 3.4.1 Summary of possible application benefits from implementation of NEWS.

Change Variable/Issue	NEWS Application Benefit
Weather & Climate	
Short Term Weather Prediction	• Establish warning system for extreme event forecasting, floods and hurricanes. • Improve short term forecasts to Decision Support Systems
Seasonal to Interannual Changes to water cycle	• Improve 10-90 days water and air temperature forecasts. • Determine and predict interannual predictions for flora and fauna distributions energy planning.
Anthropogenic Impacts	• Assess Anthropogenic impacts to water and energy cycle.
Biogeochemistry	
Carbon Cycle	•. Study and develop links with water and energy cycle.
Other Nutrients (e.g. nitrogen)	• Link water availability with nutrients for air and water quality.
Human Impacts	
Water Quality	• Improved water science/availability for assessments (e.g, concentrations, runoff etc.).
Infectious disease	• Further develop links (wet vs dry) using remote sensing.
Ecosystems	
Coastal Areas	• Assess changes to coastal areas from water cycle, sea level and wetlands loss.
Sea Level Rise	• Improve estimates of glaciers and ice sheets. • Study water budget, continental and ocean mass.
Agriculture	• Improve assessment and prediction of food production, and irrigation management. • Provide information for improved irrigation management..
Flora and Fauna Distributions	• Water and energy cycle changes significantly affects changes to flora and fauna distributions.
Water Availability	
Precipitation	• Provide local to global estimates for closing water budget. • Link to redistribution of energy through global heating.
Snow and Ice	• Improve snow extent over complex terrain • Develop techniques for snow water equivalent mapping.
Ground Water	• Direct estimates via GRACE and indirect estimates via modelingand remote sensing.
Surface Runoff	• Compensate for decline in ungauged basins. • Indirect (distributed modeling and direct (remote sensing)
Soil Moisture	• Improve from experimental to operational estimates.

4. Phased NEWS Implementation

NEWS is a coordinated research program to ***document and enable improved, observationally-based, predictions of energy and water cycle consequences of Earth system variability and change***. The long sought prediction system is built based on a global observing and assimilation system to determine the initial state of climate and a modeling system to make the forecast, both of which do not currently exist in complete or accurate form. Developing the prediction capability requires progressing through a repeating cycle of research elements: observations and retrievals, analysis, model development and testing, prediction, and demonstration of applications.

Observation*s* are necessary to describe the state of the climate system, to determine the initial conditions for a model forecast of water changes, to provide a basis for testing the fidelity of numerical model simulations as measured by the accuracy of the forecasts, and to identify critical required improvements. They are also important for the basic understanding of processes. ***Analysis*** of observational data is necessary to characterize climate variability, explore the limit of predictability of observed variations, and identify possible mechanisms through diagnostics. Further analysis or data assimilation is needed to evaluate model performance, initialize model forecast, and to identify causes of forecast errors. ***Advanced climate models*** are the necessary centerpiece of the prediction system because the climate is governed by a complex non-linear combination of coupled physical processes. Climate mechanisms can only be understood by experimenting with different (model) hypotheses. The key metrics to measure progress toward the ultimate objective of NEWS will be the accuracy of seasonal to inter-annual ***prediction****s* of changes in precipitation and of water supply. Early versions of these predictions can also be employed, through partnerships with users, to test ***applications*** to water resource management and impact assessments associated, for example, with extreme hydro-meteorological events.

The implementation plan described below is organized in three successive phases calling out specific goals and milestones, thus defining successive stages in the development, validation and improvement of each component of the prediction system described above. Some activities in these phases would overlap. The emphasis during Phase-I is to adopt a process for promoting overall program integration in support of exploiting already developed capabilities and preparing for future developments of NEWS program elements. Phase-II focuses on addressing deficiencies and building a viable "prediction" system. Phase-III, focuses on the delivery of an end-to-end system to address the ESE vision, namely: comprehensive observations to accurately quantify the state and variability of the global water cycle, including data time series data sets with no significant gaps; routine analysis of variability of storage rates, transports and fluxes; routine prediction of key energy and water cycle parameters (including clouds and precipitation, radiation interactions and energy budgets, and surface hydrological parameters) and improved energy and water cycle forecasts for use in decision support systems. This section highlights the activities and milestones within the three chronologically successive Phases of NEWS with the caveat that various sub-tasks would by necessity overlap. The overall program goal is to ensure that advances in all the components of the science problem proceed on comparable paces and converge eventually to constitute a coherent water cycle prediction system. Coordination to maintain proper phasing of the research must not compromise the flexibility to exploit unexpected results or take unanticipated pathways. Specific measures of success (metrics) will be established by NASA management as a part of the overall planning process undertaken in consultation with the NSIT.

4.1 Phase 1: Exploiting Current Capabilities and Preparing for the Future (5 years)

The first phase focuses on the first coordinated attempt to describe the complete global energy and water cycle using existing and forthcoming satellite and ground based observations, and laying the foundation for essential NEWS developments in model representations of atmospheric energy and water exchange processes. This comprehensive energy and water data analysis program must exploit crucial datasets, some still requiring complete re-processing, and new satellite measurements. These data products will then be evaluated for accuracy and consistency, in part by using them in the first diagnosis of the weather-scale (space and time) variations of the global energy and water cycle over the past one-two decades**.** The primary objective is to ensure that results of this analysis effort serve as a recognized data basis to compare with corresponding climate statistics produced by existing climate models, quantify systematic deficiencies, and identify needed improvements. The data records to be produced through these efforts are mandatory for developing and validating models that meet NEWS scientific requirements.

At the same time, this implementation plan calls for the development of radically new model representations of energy and water exchange processes that resolve significant process scales and spatial variability in ground boundary conditions. Such process-resolving models may be first constructed as independent stand-alone modules that can be tested against *ad hoc* field measurements and systematic observations at selected experimental sites. At a later stage, the codes may be simplified through statistical sampling of process-scale variables or otherwise reduced to generate integrated fluxes representative of each grid-element in a climate model. Finally, the implementation plan calls for broad exploration of potential new observing techniques concerning all aspects of the energy and water cycle, and initiating relevant technical feasibility and scientific benefit studies.

	Summary of Key Phase 1 Milestones
Observations and Retrieval	• Continue and enhance global measurements of clouds and aerosols, radiation vertical profiles • Assess methods for quantifying snowfall and mixed precipitation • Evaluate and invest in technology for observing land water storage • Evaluate global dataset adequacy and quality • Develop improved multi-sensor multivariate geophysical retrieval methods • Quantify NEWS data requirements
Analysis	• Reduce uncertainties in describing the global water/energy budget components. • Improve accuracy of precipitation and evaporation estimates • Develop new climate data products (e.g., latent and radiative heating profiles) • Quantify predictability of energy and water cycle variations (all spatial scales) • Develop diagnostic techniques for investigating how multiple feedback processes affect climate responses to forcings
Modeling and Prediction	• Improve current parameterizations of clouds and precipitation, land surface hydrology, atmospheric boundary layer and ocean mixed layer • Develop stand-alone ultra-high resolution cloud process and land hydrology models with atmospheric coupling for water/energy fluxes, soil moisture, runoff • Develop high resolution models for coupled clouds, radiation and hydrology • Test embedded process models in general circulation models • Develop and test advanced energy and water data assimilation methods • Quantify/evaluate causes/differences in precipitation predictions between global precipitation prediction models

	• Establish performance metrics for energy and water predictions
Applications	• Identify currently available data and analysis products useful for applications • Conduct selective demonstrations of usefulness of current data • Link weather & climate predictions to demonstrate use in assessments of examples of representative consequences (e.g., extreme events) • Identify observation and prediction system requirements for water management applications

Bracketed references in 4.1.1 through 4.1.4 refer to specific NEWS investigations selected through normal competitive peer reviewed channels. (see Appendix A1.3)

Observations and Retrieval

- Implement global measurements of ***cloud and aerosol vertical distribution*** (CloudSAT and CALIPSO missions) and the retrieval of cloud optical properties, particle/drop size distribution and physical properties. Develop methods for inferring atmospheric radiative heating profiles (radiation flux divergence) combining CloudSAT, CALIPSO, and MODIS/CERES/AMSR/ AIRS/PARASOL data. [P133, P179, P265, P53]

- Assess the feasibility of combining visible, infrared and microwave remote sensing to quantify ***snowfall and mixed precipitation*** in preparation for the GPM program, identify freezing or melting ground, detect surface melting on sea ice and ice sheets, and in general characterize ***cold land processes***. Examine the potential uses of CloudSAT radar data to quantify snowfall, and combined TRMM and CloudSAT data to estimate mixed precipitation. In cooperation with international partners, identify further measurement requirements for advanced GPM and Cold Land Process Pathfinder missions.[P179, D458, P143, P265, D118]

- ***Explore potential advanced remote sensing methods*** for global observation such as land water storage in the form of soil moisture (possibly at several depths), inland water bodies and other important reservoirs, river discharge, and other relevant hydrologic quantities. Invest in required conceptual studies and ***technology development***.[P133, P448, D020, P53]

- Evaluate the ***quality of global energy and water cycle datasets*** and identify important deficiencies or gaps. The accuracy, completeness, and physical consistency of datasets based on operational observations may be evaluated by comparing to short-term experimental satellite measurements, extensive field campaign data (e.g., GEWEX), and reference measurements from surface stations (e.g., ARM, BSRN). This quality assessment may also require technology investments to improve *in situ* sensors.[P133, P152, P179, P448, P170, P147, P134, P265, D114, D020, D423, D044 , P433, P053]

- Develop advanced multi-variate, non-linear, more rigorous ***geophysical variable retrieval methods*** based on physically consistent algorithms. Such development requires building new state-of-the-art radiation transfer models across the observed electromagnetic spectrum, including rigorous treatment of spectral dependence, polarization and coherent radiation.

Also required are development of more effective algorithms (e.g., neural networks) that can handle non-linear relationships among a large number of variables and efficiently apply to large volume datasets such as the combined observations of the A-train, NPP and future NPOESS.[P179, P265, D114]

- Based on existing empirical and theoretical (model) knowledge, quantify NEWS data requirements, i.e. the nature, space/time sampling, and accuracy/precision needed for the different tasks envisioned in the program. [P448, P435, P265, D423]

Analysis

- ***Using existing datasets,*** assemble a complete description of global energy and water cycle to within 15%, based on budget closure considerations, including variability and changes. In cooperation with other agencies and international partners, review existing analysis procedures and implement consistent reprocessed analyses of essential long-term global datasets. Also needed are consistent time series of atmospheric state and circulation data, derived from operational analyses of basic meteorological observations or the reanalysis of archives. In cooperation with NWP centers, seek improvements in the accuracy of divergent wind field analyses. [P152, P223, P448, P147, P134, D114, D020, D44]

- Improve the accuracy of ***precipitation and evaporation*** estimates over land and ice, and complete the datasets over continents, sea ice and ice sheets, through combined analysis of multiple satellite and surface measurements. The required additional inputs include surface skin temperature and soil wetness/melting indicators (combined infrared and microwave observations), near-surface humidity (atmospheric sounder suites), ocean surface wind velocity (active and passive microwave sensors), land-ice surface wind inferred from conventional weather observations and assimilation analysis. Merge the flux products with ***water storage information*** derived from SMOS, Aquarius and GRACE measurements. Evaluate different techniques for estimating water vapor transport. Analyze and reduce discrepancies between water vapor transport estimates and precipitation and evaporation estimates.[P133, P152, P143, D114, D020, P433]

- Develop ***new climate data products***, based on combined analyses of operational and experimental satellite measurements, and *in situ* reference measurements from surface networks such as the Baseline Surface Radiation Network, ARM-CART or similar facilities. In particular, investigate and exploit methods for inferring ***latent and radiative heating profiles*** (radiation and heat flux divergence) from vertical profile measurements by TRMM, CloudSAT, and CALIPSO, supplemented by A-train, POESS/NPOESS and METOP data. These results may be extended to longer periods using statistical models of cloud vertical structure related to different cloud systems observed by operational polar-orbiting and geostationary environmental satellites.[P133, P179, P223, P448, P435, P147, P134, D114]

- Characterize weather-scale and longer-term variations in the global energy and water cycle using available global datasets, investigate possible trends, teleconnections and potential causal relationships and quantify the ***predictability of energy and water cycle variations*** on spatial scales, from weather systems to global, and time-averaging periods. This work will yield critical new insights into the performance, strengths, and limitations of individual data sets. [P223, P147, P134, D423]

- Develop advanced non-linear, multi-variate ***diagnosis/analysis techniques*** to investigate how multiple feedback processes affect the climate response to various forcings. [P170, P435, P143, P134, D029, D423]

Modeling and Prediction

- Pursue ***improvements in current parameterizations*** of cloud and precipitation processes, land surface hydrology, and vertical transport in the atmospheric boundary layer and oceanic mixed layer. This work could be carried out using a range of models, from process-scale to regional and global, and from NWP models to fully coupled climate models, as well as additional observations. The outcome of this effort would be tested by comparing model outputs to observation-based global energy and water cycle datasets, notably surface radiation, heat, and water fluxes, and atmospheric transport data. The same non-linear, multi-variate analysis methods, developed for application to observations (see above), can be applied to model representations to assess how well dynamical relationships and extreme events are captured. [P179, P435, P265, D029, D471, D118]

- Develop ***stand-alone, ultra-high resolution cloud process models*** that can resolve energy-containing scales of cloud systems dynamics, and explicitly represent cloud condensation processes (grid-scale microphysics), cloud water and ice, cloud particle size and properties. Likewise, develop stand-alone ultra-high resolution models of ***land surface hydrology*** and coupling with the atmosphere, for model computation of energy and water fluxes, soil moisture, and runoff. Assess the value of combining both types of models into a single integrated representation of ***coupled cloud, radiation, and surface hydrology***. The outcome of this effort would be evaluated against detailed measurements from experimental sites (e.g. ARM-CART, TOGA-COARE, CEOP Reference stations) and *ad hoc* field experiments. [P448, P435, D471, D118]

- Test the above process representations as ***embedded modules in general circulation models*** (GCM) capable of producing deterministic predictions of weather events and/or realistic simulations of weather-scale variability. Assess the performance of process-resolving models embedded in GCM computations (one-way coupling) against the same data as above. [D435, D471, D118]

- Develop and test next generation energy ***and water data assimilation systems*** that can ingest relevant atmospheric and hydrologic measurements and determine initial values for regional to global model predictions of variations or change in the global precipitation and hydrologic regimes. [P179, P448, D435, P143, D029, D471, D118]

- Conduct quantitative evaluations of ***differences among global model predictions*** of the energy and water cycle over seasonal to decadal time scales, and investigate the causes for such differences. [P179, P448, P143, P134, P265]

- Establish ***performance metrics for energy and water cycle predictions*** taking into account the limits of predictability of atmospheric and hydrologic variables over a range of space- and time-scales, from regional to global, and from weather time-scale to climate change. [P448, P265]

Applications

- ***Identify currently available data and analysis products*** that are useful for applications. [P448, P435, P265]

- Link weather and climate predictions to the ***demonstration of some representative***

consequence; notably consequences of extreme events. Evaluate the extent to which the information provided by current models and data is sufficient for such applications. [P448, P435, D423]

- Identify ***observation and prediction system requirements*** for water management applications.[D423]

4.2 Phase 2: Integrating Essential Improvements into the Observation-Prediction System (5 - 7 years)

The second phase will focus on correcting the deficiencies identified in the first phase, exploiting and evaluating the newer measurements from recently deployed satellites (especially GPM), advancing multivariate analysis procedures to exploit the full range of observations, and developing new measurement approaches for future flight missions. Simultaneously, the second phase includes implementing new process-resolving or otherwise improved representations of energy and water exchange processes in general circulation models (GCM), assembling a complete end-to-end data assimilation and prediction system for seasonal and shorter-range forecasts, and testing the predictions against observed transient variations or changes in climate statistics. This will involve reprocessing of legacy data as required. An important objective of the second phase is to deliver useful seasonal predictions that can be applied to, and evaluated for their value to optimize water management decision-making.

	Summary of Key Phase 2 Milestones
Observations and Retrieval	• Facilitate the delivery of an experimental energy and water cycle observation system to acquire comprehensive observations of cloud structure & optical properties, radiation fluxes, precipitation, atmospheric circulation, aerosols, for testing CRM's, GCM's and CCM's (A-Train and other continuing observations) • Exploit Phase 1 findings in developing advanced retrieval techniques for rain/snow, water vapor, wind etc., w/sampling density to directly determine transport, divergence terms, and soil moisture, water storage and freeze/thaw events • Identify and develop innovative remote sensing methods • Compare new remote sensing capabilities with in situ data from experimental sites and/or field campaigns • Form partnerships with operational agencies
Analysis	• Apply multi-variate analysis techniques in retrospective analysis of climate variability to investigate causes of natural variability and fast feedback processes, and discriminate between forced and unforced responses • Assess climate variability (short time scales) and forcing (longer time scales) • Assess the predictability of energy and water variations on an expanded range of space and time scales
Modeling and Prediction	• Develop simplified process resolving representations of precipitation and land hydrology for GCM simulations • Evaluate conventional parametric representations of clouds, precipitation, boundary layer, land hydrology in climate models compared with weather events and observed seasonal/interannual variations • Assess similarities and differences between model climate variability on short time scales and forced responses of models on longer time scales • Improve representation of slow feedback processes • Determine most informative model products for predicting water supply • Assemble experimental end-to-end energy and water cycle prediction system from

	observations to data assimilation, model initialization and prediction, to assessments of hydrological consequences and decision support systems
Applications	• Test ability to predict consequences of extreme hydrological events • Develop prediction skill metrics aiding decision making procedures

Observations and Retrieval

- Assemble the components of an ***experimental energy and water cycle observation system*** combining operational environmental satellites, currently planned experimental satellite missions such as CloudSAT and CALIPSO, SMOS, HYDROS, Aquarius, GPM, and potential new exploratory missions (e.g. advanced remote sensing systems for solid precipitation, soil moisture, and ground water storage).
- ***Develop and implement advanced*** single- or multi-instrument ***retrieval techniques*** for estimating energy and water quantities. Develop and implement comprehensive multi-variate retrieval schemes that combine new satellite measurements (e.g. CloudSAT, CALIPSO, Aquarius, HYDROS, GPM, etc.) with conventional data from operational satellites and in situ measurements to produce consistent combined retrievals of energy and water quantities.
- ***Identify and develop innovative new remote sensing methods*** for quantifying rainfall and snowfall, measuring atmospheric water vapor and wind with the sampling density required to directly determine water vapor transport and wind field divergence, estimating soil moisture (possibly at several depths), quantifying water storage in other reservoirs, identify freeze/thaw events. Continue to invest in relevant technological developments (especially active sounding techniques, such as lidars and radars, which can resolve the lower troposphere).
- ***Test new remote sensing capabilities*** against detailed *in situ* measurements from selected experimental sites or field experiments, as appropriate.
- Form ***partnerships with operational agencies*** for the continued collection, analysis, and archival of new or expanded global energy and water cycle datasets.

Analysis

- ***Apply multi-variate analysis techniques*** to combine newly developed global data sets with older data products and determine energy and water exchanges associated with climate variability or climate change over the past few decades. Reprocessing of select legacy data sets may be required. Apply these analyses to the investigation of causes for natural variability and studies of fast feedback processes that allow discriminating between forced and unforced responses of the climate system. Quantify responses to different external forcings.

- Based on observational data sets, ***assess the similarities and differences*** between observed climate variability on shorter time scales and climate responses to forcing on longer time scales.
- Based on observational data sets, ***assess the predictability of energy and water cycle*** variations on a range of space-time scales, from weather-scale to decadal time scales and from regional variations to global change.

Modeling and Prediction

- ***Develop reduced process-resolving representations*** of cloud, precipitation and land hydrology processes suitable for implementation in GCM simulations. Such reduced representation may be based on 2-dimensional representations of the full 3-D dynamics or other methods for sampling the variability and heterogeneity of real processes within GCM grid boxes. Test the accuracy of grid-box averages of energy and water fluxes computed by such reduced representations, and ***evaluate impacts on GCM predictions*** over a large, statistically compelling ensemble of observed weather events and seasonal to interannual variations, including extreme hydrological events (floods and droughts).
- Similarly ***evaluate conventional parametric representations*** of clouds, precipitation, boundary layer, and land hydrologic processes in climate models against individual weather events and observed seasonal or interannual variations. This task will require a capability for data assimilation and initialization of boundary or reservoir variables that govern weather, transient hydrologic events, and seasonal variations.
- ***Assess the similarities and differences*** between model climate variability on shorter time scales and the forced response of climate models on longer time scales.
- Improve the representation of the ***slow feedback processes*** involving, *inter alia* exchanges between land and coastal waters, river discharge in ocean basins, etc.
- In view of the observed and modeled predictability of energy and water cycle components, identify the most informative climate model prediction and/or deterministic forecast ***products for predicting water supply***. In cooperation with water management agencies and water resource managers, design and implement tests of this capability.
- Assemble an ***experimental, end-to-end energy and water cycle prediction system*** from measurement to data assimilation, model initialization and prediction, and assessments of hydrologic consequences. The system may involve several kinds of numerical models (from regional to global, and from NWP models to interactive climate-system models) for different purposes

Applications

Applications activities are highly leveraged with external partners and funding.

- Test ability to predict the ***consequences of extreme hydrological events*** such as drought, flooding, winter storms and their environmental impacts.
- Develop ***prediction skill metrics*** relevant to applications and management decisions.

4.3 Phase 3: Completing and Validating the Water Cycle Prediction System (5 yrs)

The third phase will focus on facilitating the development of a capability for short term, and annual to decadal-scale climate predictions, in cooperation with the climate modeling community. The implementation plan calls for delivery of advanced atmospheric GCM formulations that can demonstrably predict changes in the energy and water cycle up to at least several seasons. An objective of the third phase will be testing against observations decadal predictions produced by fully interactive models of the complete climate system and/or simpler configurations involving the partial replacement of active components by observed boundary conditions. The third phase will also aim to deliver more penetrating tests of model performances using extended analyses of the widest possible range of observations, including some of the new global observing systems evaluated in the second phase.

	Summary of Key Phase 3 Milestones
Observations and Retrieval	• Complete assembly and deployment of a full experimental energy and water cycle observing system •Further development of a comprehensive data management and retrieval system • Reprocess the combined record of energy and water global observations using advanced retrieval methods
Analysis	• Characterize the slower feedback processes that effect the energy and water cycles
Modeling and Prediction	• Produce a fully interactive global climate system model that characterizes the complete energy and water cycle • Construct a comprehensive energy and water data assimilation and prediction system • Conduct a full end-to-end test of the prediction system against the past 30 to 50 year observational record
Applications	• Test the accuracy of energy and water cycle prediction products for applications to water resource management. • Demonstrate ability to predict consequences of climate change and hydrologic extremes • Demonstrate feasibility of a global hydrologic warning system

Observations and Retrieval

- Promote and contribute to the deployment of a ***full experimental energy and water cycle observing system***, consisting primarily of new and existing satellites-of-opportunity, together with new missions put forward by NEWS team members. that can support model predictions of the global energy and water cycle and hydrologic consequences.
- Further the development of a comprehensive ***data management and retrieval system***, including the advanced algorithms developed in the previous phases, that can be used by operational agencies in support of operational predictions and services; and conduct an end-to-end data system test. Special considerations will be placed on research to operations transition opportunities.
- Using advanced geophysical data retrieval algorithms, ***reprocess the combined record* of *global observations*** from the A-train, NPP, NPOESS and other operational environmental satellites, CloudSAT and CALIPSO, SMOS, HYDROS and Aquarius, GPM, and other future satellite missions.

Analysis

- Characterize the most significant ***slower climate feedback processes*** that affect decadal predictions

Modeling and Prediction

- Integrate the component process models developed in the previous phases into ***fully interactive global climate models or Earth-system models***. Evaluate the consistency of the predicted energy and water cycle on decadal or longer time scales, e.g. through verifying the balance of fresh energy and water fluxes and storage.
- Build a ***comprehensive energy and water data assimilation and prediction system*** that explicitly predicts the significant (energy containing) space- and time-scales of the energy and water cycle. Achieving this goal may involve developing a set of models with consistent physical process representations but different designs for different prediction objectives (e.g., regional, global short-term, global long-term models).
- Conduct a ***full end-to-end test*** of the prediction system against the past 30-50 year observation record to demonstrate the value of such simulations or predictions for practical applications, including the ability to predict extreme hydrologic events, out to decadal time scales.

Applications

- Test the accuracy of energy and water cycle ***prediction products for application to water resource management.***
- Demonstrate ability to ***predict the consequences*** of climate change and hydrologic extremes for specific test cases.
- Demonstrate the feasibility of an integrated ***global hydrologic warning system*** for timely identification of extreme hydrologic events of significance to society.

5. Linkages to NASA, National and International Programs

The broad national objectives of energy and water related climate research extend well beyond the purview of any single agency or program, and involve the support of activities that are essentially matched to each agency's respective roles and mission. Accordingly, NEWS will focus its priorities on scientific activities that are consistent with NASA's primary responsibilities in this area of research. In principle, NEWS does not plan to undertake significant research on all program elements, but looks to other NASA programs, other Federal agency programs, and the international community, as sources of essential data and knowledge. Examples include experimental and operational observations of air/sea fluxes, ocean circulation, atmospheric state, snow and ice; as well as support for the development of new general circulation models. In some cases, NEWS investments may be required to supplement these activities to ensure that they meet NASA needs, for example, *in situ* measurements of parameters that are essential to validating space based remote sensing, as well as quantities needed but not otherwise measured or derived.

5.1 Linkages with Other NASA Programs

The NASA Earth Science research program aims to acquire deeper scientific understanding of the components of the Earth system, their interactions, and the consequences of changes in the Earth system for life.

The energy and water cycle serves as an integrator within the Earth system connected to the other NASA themes and scientific disciplines. The energy and water cycle is itself cross-cutting, and must be studied through an integrated systems approach. It directly affects and controls the other components of the Earth system and, is conversely affected by their changes through processes involving energy and water storage, fluxes and feedbacks. These interactions occur on a continuum of temporal and spatial scales ranging from short-term weather to long-term climate and motions of the solid Earth, and from local and regional to global. Therefore, in the implementation of NEWS scientific research, it is important that the contribution and links to common NASA Earth Science goals are recognized and exploited.

Linkages with NASA Earth Science Focus Areas

NASA has established six scientific focus areas for these complex processes. These scientific focus areas are: Atmospheric Composition, Carbon Cycle and Ecosystems, Climate Variability and Change, Earth Surface and Interior, Water and Energy Cycle, and Weather. Earth Science focus areas are interrelated and must eventually be integrated to arrive at a fully interactive and realistic Earth system representation. The integration of NEWS efforts with the efforts the other focus areas is essential for the implementation of this focus area.

Linkages with Earth Science Research Disciplinary Programs

The global Earth system environment can only be understood as an interactive system including the atmosphere, oceans, and land systems. The thrust of NASA Earth Science embraces multiple disciplines (e.g., atmosphere dynamics/physics/chemistry, hydrology, biology, oceanography, and geology), and requires integrated, cross cutting focus areas, as described above. NASA goals are to obtain an understanding of the entire Earth system by describing how the component systems evolve, function, interact and may be predicted. Each of these focus areas cut across the traditional scientific disciplines reflected by the organizational structure of the Research and Analysis Division, to apply multidisciplinary scientific knowledge to Earth system processes.

Linkages with the Earth Science Applications (Applied Science) Program

Water is essential to life and directly impacts and constrains society's welfare, progress, and sustainable growth, and is continuously being transformed by climate change, erosion, pollution, and engineering practices. The water cycle is a critical resource for industry, agriculture, natural ecosystems, fisheries, aquaculture, hydroelectric power, recreation, and water supply, and is central to drought, flood, transportation-aviation, and disease hazards. It is therefore a national priority to use advancements in scientific observations and knowledge to develop solutions to the water challenges faced by society

The Earth Science goals and activities are the driving forces that help support the NASA National Applird Science Program. The Applications Program mission is to: ***Expand and accelerate the realization of societal and economic benefits from Earth science, information and technology***. The global energy and water cycle activities described in Section 2.3 and 3.2.4 will have a broad array of significant benefits to the Applications Program. Application results from the energy and water cycle research will be extensive, ranging over both multi-temporal (e.g., short-term floods to El-Nino/La Nino cycles) and multi-spatial (e.g., regional to global precipitation trends) scales.

NASA has identified twelve theme areas to exploit the Earth Science technologies (Figure 5.1). For each of the theme areas an engineering systems approach is used to incorporate remote sensing observations and modeling predictions to decision support tools. In this approach NASA data are evaluated verified/validated and benchmarked to study possible improvements. The primary emphasis of the program is to supply NASA data and information that may yield improvements to other groups, emphasizing US federal agencies having broad or national applications. The number of potential NASA partners for these application areas is large. NOAA, DOD, EPA, USDA, USBR, USGS, NMFS, NOAA-NESDIS, NIH, CDC, USFWS, BLM, FEMA, and more, plus state and local agencies (DEQ, etc.) all are potential users of a wide variety of information concerning the management of the Earth, and forecasts for future variability and change.

The primary NEWS interface with the NASA Applied Science Program, as well as with the array of energy and water related applications, will be through the recently approved NASA Water Cycle Solutions Network (WaterNet).

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Figure 5.1.1 *NASA Applications of National Priority*

Decision-making support overview – solutions network baseline

The need for understanding water cycle variability and its relationships with water availability and water-related natural hazards are well documented, and have provided a justification for wide ranging efforts to promote adequate observations (and historic reconstructions) to quantify the variability of water and energy cycle components. As outlined in the National Water Assessment Group report to the USGCRP (September 2000), opportunities exist and should be exploited for adopting Decision Support Tools (DSTs) for applying knowledge of the water cycle to the vast array of water sensitive social and economic sectors and related policy decisions and actions.

NASA's unique role is to use its view from space to improve water and energy cycle monitoring and prediction. NASA has collected substantial water cycle information and knowledge that must be transitioned to develop solutions for all twelve National Priority Application (NPA) areas. Planning is underway to develop *WaterNet*: The NASA Water Cycle Solutions Network, whose goal is to improve and optimize the sustained ability of water cycle researchers, stakeholders, organizations and networks to interact, identify, harness, and extend NASA research results to augment decision support tools and meet national needs.

Since the water cycle is fundamental to virtually all twelve NPAs, it leads to a wide range of water-related *WaterNet* partners. A sampling of the DSTs used by the water cycle community is given in Table 1. The potential application of water cycle data to the user community is very broad, spanning from local to international levels. However, the primary *WaterNet* focus will be interaction with federal agencies or groups having national or broad application of water cycle data. In this way we will be able to better encourage the use of NASA water cycle research results via existing networks and resources.

***Table 5.1.1**: A selection of Water-Cycle relevant DSTs and the potential value of NEWS research.*

NPA	Water Cycle Relevance	Example DSTs	Value & Benefit to Citizens & Society
Agricultural Efficiency	Improved production and yield prediction through water availability, and improved weather, climate, and hazard prediction	Crop Assessment Data Retrieval and Evaluation PECAD/(CADRE) POC Brad Doorn	Reduction in production costs; Better seasonal y estimates; Early warning of food shortages
Air Quality	Quantify atmospheric nitrogen deposition to water bodies as major contaminant	Community Multiscale Air Quality Modeling System (CMAQ), POC: Kenneth L. Schere	Reduction of the following: lung-related diseases, premature death, hospital admissions, etc
	Provide accurate precipitation data	Air Quality Index (AQI); POC: Doreen Neil	Improve crop resiliency/estimates; pollution reports
Aviation	Turbulence, oceanic convective weather, and ceiling/visibility, precipitation, icing	National Air Space Aviation Weather Research Program (NAS-AWRP) POC: Gloria Kulesa	Improved Safety, Improved Efficiency, Earlier warnings of hazardous weather, Reduction in the cost of flying
Carbon Mgmt	Provide accurate precipitation SM and ET for improved carbon flux estimates	Carbon Query and Evaluation Support Tools (CQUEST) POC: Dr. Christopher Potter	Improved efficiency in crop production, Climate cha mitigation
Coastal Mgmt	Providing water availability and stresses on these systems Provide accurate precipitation, salinity, and runoff data	Coral Reef Early Warning System (CREWS) POC: Jim Hendee	Alerting to coral bleaching conditions in the Florida Keys and the Great Barrier Reef
	Providing water availability and stresses	General NOAA Oil Modeling Environment (GNOME) POC: Gwen Jackson	Understand & mitigate effects of oil and hazardous materials in waters and along coasts; Improve tourism
Disaster Mgmt	Prediction, assessment, and management of drought, wildfire, hurricane, climate, flooding hazards by providing precipitation, runoff, soil moisture and snow, data.	Advanced Weather System Interactive Warning System (AWIPS) POC: TBD	Disseminate warnings including flood/forecasts in rapid, highly reliable manner
		Hazards U.S.(HAZUS), POC: Claire Drury	Identify/ Prioritize high-risk communities, Improve disaster response, Community planning
Ecological Forecasting	Biodiversity conservation and ecological sustainability, protected area management, and marine fisheries forecasting using soil moisture, precipitation and ET	Regional Visualization & Monitoring System (SERVIR) POC: Dan Irwin	Predict the impacts of changing land-use patterns & climate on ecosystem Develop ecological forecasts.
		Terrestrial Observation & Prediction System (TOPS), POC: Ramakrishna Nemani	Enhance management decisions related to floods, droughts, human health, and agricultural production.
Energy Mgmt	Energy production and efficiency using accurate global solar radiation, precipitation, snow, soil moisture, runoff.	Renewable Energy Technologies Screen (RETScreen) POC: Gregory J. Lend	Optimize renewable energy systems
		Micropower Optimization Mode (HOMER)	Finds cost effective methods of energy distribution
Homeland Security	Water supply info enabling response, recovery and mitigation to threats and military mobility prediction	Interagency Modeling and Atmospheric Assessn Center (IMAAC) POC: Stephen Ambrose	Anticipate disaster-related damage, Improve response
		Integrated Operations Facility (IOF), POC: TBD	Improve disaster response; Reduction in lives lost; Reduc in damage cost and time to recover
Invasive Species	Primary factor controlling invasive species; is accurate precipitation data	Invasive Species Forecasting System (ISFS) P Michael T. Frame	Improvement in quality of health for man, animals and plants.
Public Health	Epidemiologic surveillance systems for infectious disease, environmental health, and public health preparedness directly aided by precipitation and soil moisture	Rapid Syndrome Validation Project (RSVP)	Provide early warnings for harmful exposures, Rec environmental related diseases
		Malaria Modeling and Surveillance (MMS) POC: Richard Kiang	Increase warning time; Reduce pesticide/drug resistance
Water Mgmt	Provide accurate precipitation , snow, soil moisture, ET, and runoff data for water management decision support	RiverWare,POC: T. Flup, D. Frevert, D. Matthews, M. Brilly, G. Gregoric ; CALSIM: P. Fujitani, L. Peterson; HECRAS: D. Davis; WMS: J. Jorgeson	Forecasting and long-term water management planning, Water supply quantity and hydrologic runoff and floods
		Better Assessment Science Integrating Point & Nonpoint Sources(BASINS), POC: R. Kinseson	Improved impaired surface waters, storm water management issues drinking water source protection; Improvement in monitoring of coast area water.

*WaterNe*t will engage relevant NASA water cycle research resources and community-of-practice organizations, to develop an "actionable database" that can be used to communicate and connect NASA Water cycle research Results (NWRs) towards the improvement of water-related Decision Support Tools (DSTs). An actionable database includes enough sufficient knowledge about its nodes and their heritage so that connections between these nodes are identifiable and robust. Recognizing the many existing highly valuable water-related science and application networks, WaterNet will focus the balance of our efforts on enabling their interoperability in a solutions network context. Initially focus will be on identification, collection, and analysis of the two end points, these being the NWRs and water related DSTs. WaterNet will then develop strategies to connect these two end points via innovative communication strategies, improved user access to NASA resources, improved water cycle research community appreciation for DST requirements, improved policymaker, management and stakeholder knowledge of NASA research and application products, and improved identification of pathways for progress. Finally, WaterNet will develop relevant benchmarking and metrics, to understand the network's characteristics, to optimize its performance, and to establish sustainability. The WaterNet will deliver numerous pre-evaluation reports that will identify the pathways for improving the collective ability of the water cycle community to routinely harness NWRs that address crosscutting water cycle challenges.

Table 5.1.2: *A selection of existing water-cycle related science and stakeholder networks; examples of networks to be engaged by the WaterNet.*

Network	Description
CUAHSI	The Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) is a corporation of 100 university member institutions founded in 2001 to develop and enable a research agenda for the hydrologic science community. CUAHSI's program calls for research to be carried out at much larger spatial scales than has been done in the past, to integrate all parts of the terrestrial hydrologic cycle in addressing research questions, and to link hydrologic, chemical, and biological processes. CUAHSI's program in Hydrologic Information Systems (HIS) will create comprehensive hydrologic data models consisting of an information database coupled with tools for acquiring, analyzing, visualizing, and modeling to distribute and synthesize hydrologic data.
CBP	Columbia Basin Project is a multi-state MT, WA, ID, OR that involves a network of 175 irrigation districts, Grand Coulee Dam, and related storage facilities on the Columbia River and tributaries that produce large quantities of hydropower, agricultural products, and manage the riverine ecosystems of this region. This project is managed by Reclamation in conjunction with the Bonneville Power Administration, British Columbia Power, Canada, and state and local entities. DSTs are used in the operation and planning of water resources management in this area.
CVP	Central Valley Project of California, operated by the California Department of Water Resources, Reclamation, US Army Corps of Engineers, and a network of irrigation and power companies. The Central Valley Operations Office uses a variety of DSTs for daily and monthly operational decision-making on the 150 reservoirs and hundreds of irrigation canals and laterals through out the Central Valley.
URGOM	Upper Rio Grande Water Operations Model and network of users including the US ACE, USGS, Reclamation, and the irrigation districts and municipalities that use water from the Rio Grande Basin. This DST and user network provide water management solutions to this water scarce region which has headwaters in the San Jaun Mountains of Colorado and involves NM, TX, and Mexico, and the Colorado River Basin diversions.
GMES	GMES is a joint initiative of the European Commission and the European Space Agency , designed to establish a European capacity for the provision and use of operational information for Global Monitoring of Environment and Security (GMES).
PUB	The IAHS Decade on Predictions in Ungauged Basins (PUB) is aimed at formulating and implementing appropriate science programs to engage and energize the scientific community, in a coordinated manner, towards achieving major advances in the capacity to make predictions in ungauged basins.
GWSP	The Global Water System Project (GWSP) will undertake key cross-cutting activities such as generating an information database on global water system change, facilitating a discourse on water between the social and natural sciences, and developing scenario models for the global water system.
HELP	Hydrology for the Environment, Life and Policy (HELP) is designed to establish a global network of catchments to improve the links between hydrology and the needs of society. As a cross-cutting programme of the UNESCO International Hydrological Programme, HELP is expected to contribute to the World Water Assessment Programme (WWAP), and the Hydrology and Water Resources Programme of WMO (HWRP).
AWARE	Available Water Resource in the Mountain Environment an EU project involving Austria, Switzerland, Italy, Slovenia, and Spain, and 8 research labs and universities to establish a geo-service for tailoring models and data assimilation systems to improve forecasting and management of mountain water resources, including snowpack, floods, avalanches, and related water cycle hydrolologic processes.
EFFS	European Flood Forecast System – a consortium of EU nations studying methods to improve flood predictions and warnings in central and southern Europe, part of the EU and NATO scientific community.
UCOWR	The Universities Council on Water Resources (UCOWR) organization is comprised of about 90 universities in the United States and throughout the world. Member institutions engage in education, research, public service, international activities, and information support for policy development related to water resources. Each member university appoints four faculty members as UCOWR lead delegates. Others may join as individual members
HON	Hydrological Observatory Network-an emerging network of hydrologic observations in Europe developed to monitor global change impacts on hydrology, flood frequency and intensity, hydrologic predictions within the EU fashioned after the US CUAHSI.
ALPRESERV	Alpine reservoir sustainable management considering ecological and economical aspects within EU high alpine lakes and regions using ecological and hydrological decision-making tools and engineering management systems
GIO	A NASA Level-II Program, Geosciences Interoperability Office (GI) that is responsible for agency-wide leadership of the development, promotion and implementation of geospatial interoperability through open standards.
ESG	A NASA funded GIO project, the Earth-Sun System Gateway (ESG) is an interoperable prototype portal which enables the community to access, view, layer, and interact with dynamically updated results from NASA Earth-Sun System research, technology, education, and applied sciences programs.
DAAC	Distributed Active Archive Center (DAAC) Located at NASA/GSFC they are one of eight NASA Science Mission Directorate (SMD) DAACs that offer Earth science data, information, and services to research scientists, applications scientists, applications users, and students. Their goal is to serve users Earth science data and information needs
GLOBE	GLOBE (Global Learning and Observations to Benefit the Environment) is a worldwide hands-on, primary and secondary school-based education and science program. GLOBE is an interagency program funded by NASA and NSF, supported by the U.S. Department of State, and implemented through a cooperative agreement between NASA, UCAR. and CSU. It is also a cooperative effort of schools in partnership with colleges and universities, state and local school systems, and non-government organizations.
ECHO	The NASA EOS ClearingHOuse (ECHO) supports efficient discovery and access to Earth Science data. It is a metadata clearinghouse and order broker being built by NASA's Earth Science Data and Information System. In the ECHO community, Data Partners provide metadata

	to represent Earth Science data holdings. Client Partners develop software applications to access the Earth Science metadata.

Currently, the *WaterNet* team has formal and informal affiliations with a wide range of national and international water cycle related agencies, industry and international organizations that will be formalized and expanded as part of this project (see attached letters of commitment). Key water cycle issues of value to water management include the analysis and prediction of extreme events – floods and droughts; water supply and use, snowpack evolution and runoff, consumptive use by vegetation, evapotranspiration, surface-groundwater exchanges, stream flow, flood waves, debris flows and land slides. Hydrologic processes directly impact the management of major river systems, storage facilities, generation of hydropower, protection of life and property through flood control, and provision of water for municipal and industrial use, agricultural irrigation supplies, and protection of the riparian, instream and coastal ecosystems. The water user community has a vast array of DSTs that it uses for water resource management decisions, which range from daily and hourly decisions to monthly, seasonal, and annual planning. Water managers, for example, are in many cases the conduits for additional end-users who present themselves with practical requirements for quantitative information, whether it be for flood prediction with an impending storm to identification of suitable sites for long-term hydroelectricity production. These managers are facing ever-increasing losses in the mainstay of water resource planning--the long-term discharge hydrograph, and will need to accelerate the search for integrated alternative water cycle end product data. Aviation requires fast timely predictions of hydrometeorological conditions ranging from icing to route and terminal forecasts. They rely on remote sensing information on clouds, icing conditions, jet stream locations, turbulence and surface weather. NGATS has established a national plan for the next generation air transportation system. Emergency managers require accurate predictions of extreme events that are delivered to the decision-makers at the local level in a form that they can use to warn the public and expedite relief efforts. Agricultural users – farmers and irrigation districts – need geospatial information on the crop water requirements that they can use to manage irrigation deliveries and conserve scarce water supplies. Energy producers need to know the weather conditions that impact consumption demand and affect production ranging from severe weather to heat and cold waves. These end-users have sophisticated DSTs that input a variety of information and transform this into their specific needs for management.

Recognizing the many existing highly valuable water-related science and application networks, NEWS, together with *WaterNet*, will focus the balance of efforts on enabling their interoperability in a solutions network context. A number of existing water cycle related research and applications networks are listed in Table 2 to illustrate the viability of engaging these existing networks into the proposed *WaterNet* solutions network. These networks include users of Earth Science results (NWRs) who will participate in *WaterNet* to improve their scientific content and services to end-users and stakeholders. These networks will be engaged through personal contacts and networking as proposed below. The commercial application of NASA capabilities will only grow as new capabilities are developed to assess future changes, and thereby develop the ability to predict the effects of new commercial, regulatory and policy activities. The three phases of NEWS described in Section 4 will provide fundamental information to numerous NASA applications, such as to an early warning system for floods, and to aid the allocation of predicted available water into commercial, agriculture versus public consumption uses.

Linkages with Earth Science Technology Program

NASA's Earth Science Technology Office (ESTO) coordinates, integrates, and manages the development of advanced technologies for use in future Earth system measurements. ESTO initiatives engage scientists and engineers from NASA centers and other government laboratories, industry, and academic institutions in technological development, risk reduction, and readiness for space missions. This effort includes not only new sensors but also the data retrieval, distribution, and processing capabilities to incorporate remote sensing measurements from space into data products for Earth science research, monitoring, and a host of applications.

Two programs organize ESTO work on observation technologies. The Advanced Technologies Program implements a broad effort in technology development for observing system components while the Instrument Incubator Program develops more mature instrument and measurement technologies that are ready for initial testing including deployment in suborbital laboratories, on balloons, or in airplanes. Similarly, the Advanced Information System Technologies program develops advanced capabilities for collecting, transmitting, processing, disseminating, and archiving information about the Earth System.

Using NEWS research program needs as the focal point, ESTO will identify promising scientific and engineering concepts and will support their development. ESTO will identify capability needs from NEWS science and applications objectives and will maintain traceable links between these needs and technologies in the investment portfolio.

5.2 Interagency Partnerships

The US Climate Change Science Program

NASA's Energy and Water cycle Study (NEWS) would be a major contributor to the interagency coordinated efforts planned under the National Climate Change Science Program (CCSP) which incorporates the US Global Change Research Program (USGCRP) and the Presidential Climate Change Research Initiative (CCRI).

The strength of the USGCRP has been to facilitate coordination across Federal departments and agencies with active global change research activities, drawing on the resources and expertise of both research and mission-oriented agencies. Participants in the USGCRP include the Departments of Agriculture (USDA), Commerce (National Oceanic and Atmospheric Administration) (DOC/NOAA), Defense (DoD), Energy (DOE), Health and Human Services (National Institutes of Health) (HHS/NIH), Interior (U.S. Geological Survey) (DOI/USGS), Bureau of Reclamation (BOR), State (DOS), and Transportation (DOT); the U.S. Environmental Protection Agency (EPA); the National Aeronautics and Space Administration (NASA); the National Science Foundation (NSF); and the Smithsonian Institution (SI). The Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB) provide oversight on behalf of the Executive Office of the President.

In spite of USGCRP's significant successes over the past decade, the base of information for decision making remains inadequate. In a report commissioned by the Bush Administration, *Climate Change Science: An Analysis of Some Key Questions*, the U.S. National Academy of Sciences (NAS 2001) evaluated uncertainties and research opportunities and made a number of recommendations. At the most fundamental level, the report indicated the need to better understand the causes of warming. The changes observed over the last several decades are likely mostly due to human activities, but we cannot rule out that some significant part of these changes is also a reflection of natural variability."

The report also identified areas where additional research is crucial. These included the magnitude and nature of future human-caused "forcings" such as emissions of greenhouse gases; the carbon cycle; "feedbacks" caused by water vapor, ice, and other factors that determine the response of the climate system; regional and local climate change consequent to an overall global level of change; the nature and causes of natural variability; and the direct and indirect effects of the changing distribution of aerosols (including black carbon). In addition, the report also called for accelerated research on the interactions of environmental change and human societies, including interdisciplinary research on coupled human-environment systems; integration of knowledge, including its uncertainty, into decision support systems; and regional or sectoral research into the response of human and natural systems to multiple stresses. Finally, the report noted that an effective strategy for advancing the goal of understanding climate change will require enhanced global observing systems; large-scale modeling; and more effective management of resources to ensure innovation, effectiveness, and efficiency.

CCRI introduces a new dimension to the research carried out under the USGCRP. Over the coming decade, the objective of Federally supported research programs will be to help government, businesses, and communities make informed management decisions about global environmental changes, such as climate change, given persistent uncertainties. Realizing this vision will require the continuation of research on how the Earth's climate and environment are responding to simultaneous changes in both natural forces and human activities. The USGCRP and CCRI will also develop new ways to transform scientific information into products for routine use by government and the private sector for reducing risks and taking advantage of opportunities resulting from global change.

Working as an integrated program, the USGCRP and CCRI will accelerate the transition of scientific knowledge to applications for use in resource management, disaster preparedness, planning for growth and infrastructure, and environmental and health assessment, among other areas. Partnerships with operational entities and associations in the private sector, and state and local governments, will be essential for focusing research and meeting the growing demands for relevant information to, for example:

- Reduce uncertainties for farmers by improving lead times and specificity of seasonal climate forecasts, enabling farmers to plant crops best suited to weather and environmental conditions.
- Facilitate continued safe and economic management of dams and other reservoirs by providing integrated forecasts of water demand and availability
- Support strategies for managing carbon by preparing periodic assessments of changes in carbon sources and sinks resulting from variations in climate, soil conditions, nutrients, and other factors
- Increase energy security and reduce the potential for climate-related shortages by developing the capacity to routinely forecast the implications of seasonal variations in climate for regions of the United States

The CCSP Global Water Cycle Research Program (GWC)

The global energy and water cycle is represented under the CCSP (USGCRP + CCRI) by the CCSP Global Water Cycle Program (GWC). The energy and water cycle is directly involved in all "themes" of the CCSP including all the major observational, process research, and climate prediction and applications objectives of the CCSP. Indeed, most the major sources of uncertainty in climate change predictions/projections involve GWC processes such as water vapor, precipitation, and cloud-radiation feedback among others. For the assessment of the impacts of climate variability and climate change, changes in water cycle parameters are even more important than temperature changes in the context of agriculture, water resources, ecosystems, energy, and social and economic sectors.

NASA's NEWS is fully integrated with the science and applications objectives of the CCSP-GWC which addresses the following overarching/strategic science and societal questions/issues:

- How does water cycle variability and change caused by internal processes, climate feedbacks and human activities influence the distribution of water within the Earth System, and to what extent is this variability and change predictable?
- What are the potential consequences of global water cycle variability and change for society and the environment, and how can knowledge of this variability and change improve water-cycle dependent decisions?

US Agencies with major programs and activities relevant to NASA's NEWS's research objectives include, the Department(s) of Commerce (DoC), Energy (DoE), Interior (DoI), Agriculture,(DoA) the National Science Foundation (NSF), and the Environmental Protection Agency (EPA). These other programs provide substantial research, observational (especially, in-situ) and operational applications assets which compliment NASA's areas of specialization.

Examples of interagency collaboration between NASA's Energy and Water Cycle and the programs of other agencies include NASA/NOAA jointly funded CPPA (GEWEX Climate Prediction Program for the Americas) projects on improving water demand analysis and prediction for water managers using a combination of satellite, radar and surface observations, and numerical weather forecasts, with land surface modeling to integrate Land data Assimilation Systems (LDAS) information into water operations decision support systems. The above and other projects also include active collaborations with agencies such as BOR, USDA/ARS and USGS. Coordinated activities in field campaigns include those with DOE/ARM for cloud, radiation and process modeling. NASA research collaborations include those with various efforts under NSF in the research development of improved observations and models for weather forecasting, seasonal-to-interannual (and longer) climate variability predictions and climate change projections.

5.3 International Partnerships

NASA's energy and water research connection to the international science community is through the World Climate Research Programme (WCRP), especially the Global Energy and Water Experiment (GEWEX), but including aspects of CLIVAR and CLiC. GEWEX has overall international WCRP responsibility for providing an interface with all the national space agencies with respect to energy and water cycle related global climate research requirements, instruments, data, science support. The GEWEX emphasis on improved coupled land-surface and atmosphere representations in prediction models at all scales has illustrated the direct links to the water cycle and has provided increased importance of both existing and future satellite sensing of the land and near surface parameters. GEWEX has set the stage for broader issues to be addressed within IGOS, and the Earth System Science Partnership (ESP) activities.

For example, the Global Water Cycle theme has been established by the IGOS Partnership, in which NASA plays a major role, to develop and promote strategies to maintain continuity for observing systems for the global water cycle and to progress towards an integrated water cycle observational system that integrates data from different sources (e.g., satellite systems, in-situ networks, field experiments, new data platforms) together with emerging data assimilation and modeling capabilities. It provides a framework for guiding decisions regarding priorities and strategies for the maintenance and enhancement of observations to support: monitoring of climate variability and change, effective water management and sustainable development of the world's water resources, societal applications for resource development and environmental management, specification of initial conditions for numerical weather and water forecasts and monthly to seasonal climate predictions and, research directed at priority water cycle questions. The theme also promotes strategies that will facilitate the acquisition, processing and distribution of data products needed for effective management of the world's water resources. To achieve these goals the initial activities will rely on the space based and in-situ networks that are either currently in place or planned. Furthermore, it must engage the global community through multiple linkages to global programs and coordinated activities.

In the context of global change, the Global Water System is defined as the suite of interacting physical, chemical, biological and human components that constitute and influence the fluxes of water on Earth, including the various uses of water for human well-being. The Global Water System Project (GWSP), jointly sponsored by IGBP, IHDP, WCRP and DIVERSITAS addresses the threatened sustainability of the global water system to a growing demand for water in many regions, exceeding water availability, and the degradation of water quality and subsequent ecosystem health effects associated with extreme events such as floods and droughts. GWSP will stress regional studies over a wide range of space and time scales associated with the processes that control water availability and quality.

These GEWEX related projects have already defined some paths and linkages for above initiatives and have shown areas where direct connections to the water resource societal applications can be made more cost effective. GEWEX helps NASA leverage international resources, providing added value to new satellite data, assisting in bringing in added satellite calibration/validation data sources, and delivering independent observationally-based data sets for evaluating model 4-dimensional data assimilation (4DDA) and prediction capabilities on a regional and global basis. For example, the ongoing WCRP Coordinated Enhanced Observing Period (CEOP) management is designed to take advantage of the new NASA Earth observing satellites to document and simulate energy and water fluxes and reservoirs over land, regionally, on diurnal to annual scales, and transfer this knowledge to the global scale for water resources applications.

Specific GEWEX radiation, hydrometeorology, modeling, and energy and water cycle related prediction projects which contribute to meeting NASA Earth science objectives, and benefit from major NASA investments in both resources and scientific staff involvement include:

- International Satellite Cloud Climatology Project (ISCCP)
- Surface Radiation Budget (SRB) Project
- Global Precipitation Climatology Project (GPCP)
- Global Aerosol Climatology Project(GACP)
- Surface Turbulent Air/Sea Flux Study (SeaFlux)
- Baseline Surface Radiation Network (BSRN)
- GEWEX Cloud System Study (GCSS)
- GEWEX Global Land/Atmosphere Study(GLASS)
- Global Soil Wetness Project(GSWP)
- GEWEX Atmospheric Boundary layer Study (GABLS)

- International Satellite Land-Surface Climatology Project (ISLSCP)
- GEWEX Climate Prediction program for the Americas (CPPA)
- GEWEX Coordinated Enhanced Observing Period (CEOP)

NASA has also played a leading role in the international management and coordination of GEWEX as a U.S. national contribution to the WCRP for the past decade. In this context, NASA provides primary financial support to the International GEWEX Project Office (IGPO) operated by the University of Maryland, Baltimore County through a grant administered in conjunction with a Cooperative Agreement with the Goddard Space Flight Center. The IGPO provides the primary organizational support for planning and implementing the full range of GEWEX observations, modeling, and data management activities and serves as the principal WCRP interface with NASA and the other space agencies. This NASA-University affiliation provides a unique opportunity to explore a wider range of applications on human dimensions and environmental policy issues through engagement of the policy science and engineering faculty. The IGPO will also serve on the Executive Board of the IGOS Water Cycle theme.

New opportunities for promoting effective international coordination of space-based Earth observing systems will be made available through arrangements resulting from the first Earth Observations Summit, held in Washington DC in July 2003, with subsequent sessions in Tokyo and Brussels in 2004. NASA will play a central role in the *ad doc* Group on Earth Observations (GEO), established to improve coordination of strategies and systems for earth observations and to identify measures to minimize data gaps, with a view to moving toward a comprehensive, coordinated, and sustained Earth observation system or system

6. Management

6.1 NEWS Science Integration Team (NSIT)

Integration of the science activities to serve the overall purpose of NASA by acting as an interface with other ESE research foci and activities, coordinating the execution of the NASA Water and Energy Focus Area Implementation Plan, and leading specific studies needed for integration of the results of independent product-driven or discovery-driven investigations. Exchanges of energy and water within the Earth system involve a multiplicity of interactive processes. Understanding and predicting these processes require a multi-disciplinary research program, innovative observing tools, and advanced model developments. Organizing these activities calls for a dedicated NEWS Science Integration Team (NSIT) to ensure that needed integration of various NEWS projects and linkages with partners and NASA system components are efficiently applied to serve NASA Earth Science priorities. Pursuant to the overall NASA goal of understanding the Earth system and applying Earth system science to improving the prediction of climate, weather and related natural hazards, the Associate Administrator for Earth Science established a NASA Energy and Water cycle Study (NEWS) Science Integration Team (NSIT).

The NSIT, whose mission is the integration of the science activities to serve the overall purpose of NASA by acting as an interface with other ESE research foci and activities, coordinating the progress of NEWS investigations, and enabling specific studies needed for integration of the results of independent product-driven or discovery-driven investigations. The NSIT will be comprised of scientists closely associated with NASA whose primary responsibility is to support NEWS investigations and integrate their research results to address NASA-ESE science questions. The NEWS science integration team will help the NEWS program manager develop interfaces with and improve NASA system components, and to coordinate and integrate the results of the NEWS product- and discovery-driven investigations. The NSIT will work with NEWS investigations to implement their results into a larger coordinated product, such as a NASA model, data system, integrated global data sets, etc. Since some of the NSIT tasks cannot be fully specified until the NEWS product-driven and discovery-driven investigations are selected and negotiated, the NSIT must be flexible enough to continuously reevaluate and respond to needs and gaps in the NEWS program to prevent bottlenecks that impede progress. The NEWS team will be comprised principally of the NEWS discovery-driven, product-driven, and integration investigations, but will also be open to any relevant water and energy cycle investigator. The NSIT will provide a pathway for the results of NEWS investigations to be implemented and retained as NASA system components.

In the NEWS context, “integration” means that resources must be specifically combined and applied to diagnose the key exchange processes within the energy and water cycles. Also, rigorous analyses of uncertainties are important to establish benchmarks of knowledge for observations and prediction parameters. These processes and parameters must necessarily include radiative/heat exchanges, the transport of water vapor (in the atmosphere) and liquid water (i.e. runoff and river discharge into the oceans), but emphasis is also to be placed on the main water transformations, such as: evaporation from the surface (both land and ocean), snowmelt, and the formation of clouds and precipitation. Surface-atmosphere interactions (including the atmospheric boundary layer) and cloud processes are crucial areas of research.

The NSIT will develop with each selected NEWS project, a plan for making progress towards the NEWS challenge, and formulate a NASA partnership plan as appropriate. NSIT activities will ensure that the NEWS program fulfills the core requirements of the Implementation Plan of the NASA Water and Energy Cycle Focus Area, and makes decisive progress in documenting and enabling improved observationally-based predictions of water and energy cycle consequences of Earth system variability and chance according to the Implementation Plan. The parties will settle on project metrics, including a baseline against which project progress and outcome can be measured. Subsequently, there will be a requirement for short reports based on a common format, in addition to presentations at one annual meeting of the entire NEWS team.

Specific NSIT responsibilities include:

- NEWS science integration
- Data product integration
- PI coordination
- Linkages to NASA Earth science system and technology components
- Promoting interdiciplinary Earth science
- NEWS science gap filling
- Advocating science that must be done, but was not proposed and/or funded
- Support NEWS administration functions
- Organization of energy and water related scientific meetings and conferences
- NEWS planning and vision statements
- POC responsibilities for selected NEWS in vestigations
- Implementation Plan updates
- Representing NEWS to national and international partners

Point Of Contact (POC) responsibilities:

- Developing close communication with the PIs during the course of their research, periodic assessments of their progress.
- Visiting the PIs institutes as needed
- Collaborating with PI's (to provide linkages for PI feedback and guidance in the broader context of NEWS scientific goals).
- Integrating PI research products and discoveries with other NEWS investigations.
- Evaluating overall effectiveness of research results in meeting NEWS goals.
- Reporting progress to NEWS Science Integration Team (NSIT) members.
- Encouraging/developing/providing pathways for integration/handoffs of PI projects with NSIT and NEWS team projects.
- Providing critical evaluation and recommendation of project progress, timing, and direction to NEWS program manager.
- Identifying and recommending steps to mitigate gaps and anticipate serious impediments to progress.

NEWS planning and review activities:

- Recommending NEWS Implementation Plan updates.
- Assisting ESE in the preparation of new research solicitations relevant to Global Energy and Water Cycle research.
- Assessing gaps in the execution of NEWS Implementation Plan and making suggestions to NEWS program to bring possible gap fillings through solicitation and non-solicitation processes.

- Reviewing the performance of NEWS Discovery-driven and Product-driven individual research projects and assessing the overall progress toward achieving the established goals of NEWS.
- Assisting ESE in developing new budget initiatives for NEWS-relevant research and/or observing systems elements.
- Assisting earth science disciplines in the peer review process for NEWS-relevant proposals.
- Defining and evaluating performance metrics.
- Supporting periodic program assessments.

6.2 NEWS Data Integration Center (NDIC)

There currently exists no comprehensive effort to integrate model, satellite and in-situ datasets that are required to quantify the rate and variation of water and energy cycling throughout our global environment. Emerging data collection, integration, modeling, management, distribution, and analysis technologies provide a unique opportunity for provision of integrated water and energy cycle datasets to various user communities. In order to address the NEWS challenge outlined above, NEWS will require integration and interpretation of global water and energy cycle changes in the vertical fluxes, the amount of storage, and lateral fluxes.

As a first-order science integration task, steps are required to establish a NEWS Data Integration Center (NDIC), whose purpose is to serve the overall NEWS team and its partners by compiling, integrating, diagnosing and disseminating water and related energy cycle observations and predictions that are required to pursue the NEWS challenge. Data integration is multifaceted: (a) spatial-temporal rectification allowing intercomparison and quality evaluation of disparate data; (b) physical data and error constraints using four dimensional data assimilation techniques, and (c) interconnection of disparate NEWS research teams. A key NDIC task is enable the quantification of global water cycling rates, which requires global data integration for vertical water fluxes, land water storages, and lateral land water fluxes. These observations will provide the basis for the NEWS team to develop: diagnostic trend studies, transient variability and predictability; model validation; and initialization.

Essentially, the NDIC will integrate and interpret past, current and future global space-based and in-situ water and energy cycle observations and model predictions to instill improved water and energy cycle understanding and information into global prediction, application, and education systems. The NDIC will mostly serve the NEWS team, but will also be open for collaboration with a large number of scientists, educators, managers, and research organizations to quantify the rate of global water and energy cycling through integration and interpretation of information on global changes in the vertical fluxes, storages, and lateral fluxes. The NDIC will be advised and managed by a small oversight group comprised of NSIT and NEWS team members. Key functions of the NDIC include:

- Coordinate individual NEWS projects to form a unified virtual-space NEWS data center, to establish the NEWS products in consistent formats, and to integrate the NEWS data into both WEC processes and components based products.
- Develop a framework for sharing IT resources for NEWS.
- Coordination of global data analysis, including the development of a common framework for data product processing, analysis and dissemination, developing an integrated

processing plan, and assessing the physical consistency of products as a function of weather and climate regimes.

- Identification and acquisition of global water and energy cycle observations and model predictions from all relevant sources, over the longest available period. Potential sources include: EOS satellites (Terra, Aqua, Grace, TRMM, etc), Non-EOS satellites (AVHRR, GOES, ENVISAT, ERS, JERS, etc), climate and weather models (NCAR, NCEP, ECMWF, DAO, COLA, etc.), operational networks (radiosonde, surface networks, etc.), and field experiments (LBA, GAPP, etc), etc.
- Integration of global water and energy cycle data, through: (a) spatial and temporal rectification to allow intercomparison and quality evaluation of disparate model and observation data; (b) physical rectification or constraint of data and its error using four dimensional data assimilation and modeling techniques, and (c) interconnection of disparate water cycle research teams.
- Recognizing the immense size and diversity of available water cycle data, a comprehensive data management strategy will be established to organize and link to local and distributed data resources. Whenever possible, virtual and meta data links will be established to existing data archives, rather than explicitly downloading them.
- Provide researchers, educators, and applications “one stop”, streamlined access to coordinated, geolocated, and integrated water cycle data and visualizations from all sources using innovative and community adopted tools such as GrADS-DODS Server (GDS) GDS, interactive web services, and automated processes. The GrADS (Grid Analysis and Display System) –DODS (Distributed Oceanographic Data System, also known as OPeNDAP (Open source Project for a Network Data Access Protocol)) is a freely available, powerful, yet secure data server that provides sub-setting and analysis services across the internet.
- Create a collaborative environment to attract (both virtually and physically) visiting scientists, application specialists, and educators to the NDIC to work with NEWS water and energy cycle data.
- Provide a science and information link to other major global cycles, such as the carbon cycle, solar processes, solid earth processes, and deep ocean dynamics.

The NSIT has identified the need for the NDIC, and perceives its primary value to be improved efficiency of centralized data storage, value in having a common data framework, value in providing provisional analysis tools, and providing standardized mode of interpolation (simple form in one place)

The primary components of the NDIC are (1) a data manager who will have the responsibility for managing the database and assuring data continuity and user access, (2) a disk farm of sufficient size to handle the NEWS shared data resources, (3) modest computing and software resources for mining, manipulating and analyzing data holdings, and (4) a high-bandwidth connection to the NEWS team. NDIC will be assisted by the NSIT in

- Coordinating and monitoring modeling related projects funded across NASA programs and ensuring that techniques to assimilate NASA water and energy cycle observations are made available.
- Encouraging the development of coupled data assimilation methods for optimal treatment of process-scale physics and observations.
- Encouraging the coordinated development of process resolving models.
- Enable the identification of predictable variations of global water and energy cycles, and the determination of associated climate anomalies.

- Investigating coupling of climate components and causes of global energy and water cycle variability.
- Coordinating coupled water and energy cycle modeling and observing efforts. NSIT will provide suggestions and advices to the NEWS and community-at-large modeling projects to test and evaluate their model and assimilation results with the global WEC products obtained by the NEWS program, and use the combined model and observation efforts to investigate the WEC variability and to predict water-related weather and climate events.
- Evaluating adequacy and diagnose variability of NEWS investigation products and NASA WEC products to provide WEC trend and variability diagnostics.
- Quantifying the global water and energy cycles' mean state and variability; assess accuracies of global estimates, from weather to climate scales.
- Evaluating model WEC products to provide trend and variability information.
- Improving understanding of water budget dynamics at the land surface through assessing the historical surface soil moisture information content in passive microwave satellite data record.
- Developing advanced multi-sensor (Bayesian) algorithms for estimating land surface moisture and surface-atmosphere fluxes.
- Diagnosing climate state variations using advanced non-linear approaches.
- Providing end-user decision support & solution network connections

NEWS Science Gap Filling

NSIT gap filling will be a highly dynamic task that will iterate approved NEWS investigations with overall project goals and recommend new initiatives. Examples of currently assessed science gaps include:

<u>Precipitation</u>:

- Event-based statistics of precipitation not only serve as a fundamental gauge for global water cycling, but changes in the event-based features of precipitation may have profound impacts on the global biogeochemical cycles (and therefore may affect strong feedbacks in the global carbon/climate system).
- Bridge precipitation investigations under the auspice of the aforementioned scientific motivation.
- Bridge scientific findings from other NEWS PIs (as the necessity for such integrations become evident). This would include characterizing the global, event-based statistics of precipitation based on TRMM-constellation and NEWS product-driven precipitation products.
- Assess the consistency between precipitation (and event-based statistics) and water-vapor products. A potential metric of consistency would include (among others) calculation of the spatio-temporal co-variability between atmospheric vapor residence time and precipitation frequency, intensity, and duration.
- Assess the impact of the observational event-based precipitation statistics on estimated global hydrologic (i.e. evaporation and runoff/river discharge) and ecologic (carbon, nitrogen and methane) fluxes. This model-based activity would leverage off of the carbon model activities, and Global Land Data Assimilation product-driven activities, and the global hydro-ecologic modeling activities.

<u>Atmospheric integrated moisture and heat budgets:</u>

- The NSIT could combine satellite measurements of sea surface evaporation (E) and sensible heat (H), atmospheric column water vapor (V), horizontal atmospheric moisture transport (MT), precipitation (P), cloud water path (W), longwave (LW), shortwave (SW) and net (NR) radiation, and latent heat (L) release from precipitation and cloud (LP and LW) during A-train era to produce a unified product for atmospheric integrated moisture and heat budgets over oceans. The NSIT will make recommendations for the NEWS projects related atmospheric moisture and heat satellite measurements to produce consistent data products among these projects. The spatial and temporal resolutions of the NSIT integrated product will be in both fine (0.25°×0.25°, daily) and common (2.5°×2.5°, monthly) modes.
- Based on these moisture and heat components, the atmospheric horizontal sensible heat transport (HT) will be evaluated, which will have the observational based atmospheric heat transport estimation over oceans

Atmospheric profile and radiance data assimilation:

- Research to optimally assimilate atmospheric profiles and radiance data from AIRS into regional assimilation systems including the Local Analysis and Prediction System (LAPS) and the Gridpoint Statistical Interpolation (GSI) System is currently a gap in the NEWS program.
- Take advantage of the high spatial and spectral resolution of the AIRS instrument to improve the initial representation of atmospheric stability. A second NEWS-related project involves the continued development of a land surface data assimilation technique within the WRF modeling systems designed to simulated improve land surface/ atmosphere interactions.
- Include MODIS SST and AIRS profiles into WRF regional data assimilation systems to improve the representation of initial cloud distributions and subsequent simulated precipitation, and the adaptation of GOES-based land surface data assimilation technique within WRF to incorporate 1-km MODIS skin temperature data.

Appendices

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A3 NEWS Selected Proposals

Discovery			
Ref. #	**PI**	**Institution**	**Project Title**
D020	Jay Famiglietti	UC Irvine	A Study of the First Global Measurements of the Water Cycle
D209	Allen Betts	AR	Understanding the Coupling of Surface, Boundary Layer, Cloud and Radiative Processes in the Global Water and Energy Cycle
D044	John Roads	UCSD	Global Water and Energy Budgets
D114	William Olson	GSFC	Calibration and Analysis of Global Latent Heating Estimates Using Passive and Active Microwave Sensor Data
D118	Ruby Leung	BPNL	Aerosol Effects on Cold Season Orographic Precipitation and Water Resources in the Western US
P226	Randy Koster	GSFC	Effects of Land-Atmosphere Coupling Strength and Soil Moisture Initialization Uncertainty on Subseasonal Rainfall and Temperature Prediction
D423	Siegfried Schubert	GSFC	On the Causes and Predictability of Multi-Year North American Droughts with Applications to Drought Monitoring and Water Management
D471	Scott Denning	CSU	A Global Vegetation Modeling System for NEWS
Product			
P053	Frank Wentz	RSS	A Hydrologically-Consistent Multi-Satellite Climatology of Water Vapor Transport, Evaporation and Precipitation Over the Oceans
P133	Tim Liu	JPL	Oceanic Influence on Global Hydrological Cycle
P134	Brian Soden	U. Miami	The Sensitivity of the Global Water and Energy Cycles: An Integrated Assessment of Models and Observations
P143	Mike Bosilovich	GSFC	Evaluation of NASA's Global Water Cycle Data: Interannual Variability, Interdecadal Changes and Trends
P147	Tristan L'Ecuyer	CSU	New Satellite Energy Balance and Water Cycle Products for the Study of Interactions between Atmospheric Hydrology and the Earth's Radiation Budget
P152	Bob Adler	GSFC	Global Precipitation Analysis for Climate and Weather Studies
P170	Eric Fetzer	JPL	A Merged Atmospheric Water Data Set from the A-Train
P179	Bruce Wielick	Langley	An A-Train Integrated Aerosol, Cloud, and Radiation Data Product
P223	Judy Curry	GT	Global Analysis of Ocean Surface Fluxes of

			Heat and Freshwater
P433	Soroosh Sorooshian	UC Irvine	The Challenges of Utilizing Satellite Precipitation Data for Hydrologic Applications
P435	Christa Peters-Lidard	GSFC	NASA Model and Observation Products for the Study of Land Atmosphere Coupling and its Impact on Water and Energy Cycles
P448	Matt Rodell	GSFC	Integration of Energy and Water Cycle Research Products in a Global Land Surface Modeling and Assimilation System

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A5 Acronyms

4DDA four dimensional data assimilation
ACT Advanced Component Technology
AIRS Atmospheric Infrared Sounder
AIST Advanced Information Systems Technologies
AMASS Data technology company
AMIP Atmospheric Model Intercomparison Project
ANSI/AIIM MS66 File storage management systems
Aqua NASA Earth Observing Satellite mission for water
ARM-CART Atmospheric Radiation Measurement/Cloud and Radiation Testbed
ASTER Advanced Spaceborne Thermal Emission and Reflection Radiometer
Aura NASA Earth Observing satellite mission for ozone, air quality and climate
AWARDS Agriculture Water Resources Decision Support
BLM Bureau of Land Management
BSRN Baseline Surface Radiation Network
CALIPSO Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAMEX Convection and Moisture Experiment
CCRI Climate Change Research Initiative
CCSP Climate Change Science Program
CDC Center of Disease Control
CEOP Coordinated Enhanced Observing Period
CEOS Committee on Earth Observation Satellites
CERES Clouds and the Earth's Radiant Energy System
CLIC Climate and Cryosphere Project
CLIVAR Climate Variability and Predictability
CloudSAT Cloud Satellite
CMIP Coupled Model Intercomparison Project
CREW Center for Research on Environment and Water
CRM Cloud-Resolving Models
CT Computational Technologies
DBMS Database Management System
DEQ Department of Environmental Quality
DISCOVER Distributed Information Services for Climate & Ocean Products & Visualizations for Earth Research
DIVERSITAS international global environmental change research programme
DMSP Defense Meteorological Satellite Program
DoC Department of Commerce
DoD Department of Defense
DoE Department of Energy
DoI Department of the Interior
DoSDepartment of State
DoT Department of Transportation
DSS Decision Support Systems
Terra Earth Observing Satellite to measure the land surface
EPA Environmental Protection Agency
ESEEarth Science Enterprise
ESSP Earth System Science Pathfinder
ESTO Earth Science Technology Office
ENVISAT European satellite to measure land, ocean, atmosphere and ice caps
European METOP Europe's first polar-orbiting satellite
FEMA Federal Emergency Management Agency
FSMS File Storage Management Systems
GABLS GEWEX Atmospheric Boundary Layer Study
GACP Global Aerosol Climatology Project
GAPP GEWEX Americas Prediction Project
GCIP GEWEX Continental-Scale International Project
GCM General Circulation Model
GCOS Global Climate Observing System
GCSS GEWEX Cloud System Study
GEOSS Global Earth Observing System of Systems
GEWEX Global Energy and Water Experiment
GIS Geographical Information System
GISS Goddard Institute for Space Studies
GLASS GEWEX Global Land/Atmosphere Study
GMAO Goddard Model Assimilation Office
GPCP Global Precipitation Climatology Project
GPM Global Precipitation Measurement
GRACE Gravity Recovery and Climate Experiment
GSFC Goddard Space Flight Center
GSWP Global Soil Wetness Project
GWC Global Water Cycle
GWSP Global Water System Project
HHS Health and Human Services
HSPF Hydrological Simulation Program-Fortran
Hydros Hydrosphere State mission
ICESat Ice, Clouds, and Land Elevation Satellite
IGBP International Geosphere-Biosphere Program
IGOS Integrated Global Observing Strategy
IGPO International GEWEX Project Office
IHDP International Human Dimensions Program on Global Environmental Change
IIP Instrument Incubator Program
IKONOS high resolution satellite imagery
ISCCP International Satellite Cloud Climatology Project
JCSDA Joint Center for Satellite Data Assimilation
JPL Jet Propulsion Laboratory
Landsat and EO-1 Land satellite Earth surface imaging
LaRC NASA's Langley Research Center
LCLUC Land-Cover/Land-Use Change

LESLarge Eddy Simulations
LIS Land Information Systems
MISR Multi-angle Imaging SpectroRadiometer
MODIS Moderate Resolution Imaging SpectroRadiometer
MSFC Marshall Space Flight Center
NAS National Academy of Sciences
NASA National Aeronautics and Space Administration
NCEP National Centers for Environmental Prediction
NESDIS National Environmental Satellite, Data, and Information Service
NEWS NASA Energy and Water cycle Study
NIHNational Institute of Health
NLDAS North American Land Data Assimilation System
NMFS National Marine Fisheries Service
NOAA National Oceanic and Atmospheric Administration
NPOESS National Polar-orbiting Operational Environmental Satellite System
NPP NPOESS Preparatory Project
NSF National Science Foundation
NSIT NEWS Science Integration Team
NWP Numerical Weather Prediction
OMB Office of Management and Budget
OSTP Office of Science and Technology Policy
QuikSCAT Satellite mission for ocean surface wind measurements
RiverWare Water Management Decision Support Tool
RSPRadiation Sciences Program
SAR Synthetic Aperture Radiometer
Sea Flux Surface Turbulent Air/Sea Flux Study
SI Smithsonian Institution
SMOS Surface Meteorological Observation System
SORCE Solar Radiation and Climate
SPoRT Short-term Prediction Research and Transition
SRB Solid Rocket Booster
STAR Synthetic Thinned Aperture Radiometer
SWAT Soil and Water Assessment Tool
SWE Snow Water Equivalent
SWWG Surface Water Working Group
Terra NASA’s Eart Observing Satellite mission for land
TM Thematic Mapper
TMDLs Total Maximum Daily Loads
TOA Top Of Atmosphere
TRMM Tropical Rainfall Measuring Mission
UniTree, permanent mass storage system of data.
USBR US Bureau of Reclamation
USDA US Department of Agriculture
USFWS US Fish and Wild life Service
USGCRP US Global Change Research Program
USGS U.S. Geological Survey
UT Upper Troposhpere
WCRP World Climate Research Programme

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